ALTERNATE-DAY FEEDING OF A MONENSIN-CONTAINING ENERGY SUPPLEMENT TO GROWING CATTLE ON WHEAT PASTURE AND POTENTIATION OF THE MONENSIN RESPONSE BY SALT

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CHAPTER 1

INTRODUCTION

Wheat pasture is regarded as a source of high quality forage capable of producing rapid rates of gain for ruminant livestock. However, the chemical characteristics of this forage may also limit animal performance. Wheat forage commonly has DOM and CP levels which approach 75% and 30% of total forage DM, respectively, with much of the N present as NPN (Horn, 1984). Stewart et al. (1981) reported that K concentrations of wheat forage in El Reno, OK often were greater than N concentration and regularly exceeded 4% of DM. Mayland et al. (1976) reported K concentrations of hard red spring wheat forage ranging from 3.1 to 3.3% between mid-April and mid-May. Sodium concentrations of forage are, however, typically low and may vary from 0.12 to 0.55% of DM (Morris, 1980).

The high CP levels of wheat pasture can result in low forage DOM:CP ratios. Hogan (1982) reported that a DOM:CP ratio of less than 4:1 is condusive to the loss of large amounts of N from inefficient microbial protein synthesis. Energy supplementation increases the DOM:CP ratio and supplies energy for microbial synthesis. In the past, energy supplementation of growing cattle on wheat pasture has served primarily to allow increases in stocking density

by substituting silage or grain for wheat forage (Horn et al., 1995). Increases in daily gain of cattle grazing wheat pasture without changes in stocking density from energy supplementation of cattle grazing wheat pasture have also been previously observed (Horn et al., 1988, 1990; Beck et al., 1993; Andrae et al., 1994).

Inclusion of monensin in energy supplements increases daily weight gains of beef cattle consuming forage diets approximately .09·kg·hd^{-1}·d^{-1} (Potter et al., 1986), and has decreased the incidence and severity of frothy bloat (Branine and Galyean, 1990; Grigsby, 1984). However, decreased ionophore effectiveness has been observed *in vitro* in the presence of high K levels (Dawson and Boling, 1987). Increased ionophore effects have been reported at high K levels when Na levels were increased both *in vitro* (Dawson et al., 1983; Schwingel et al., 1989) as well as *in vivo* (Rumpler et al., 1986; Spears and Harvey, 1987). Increasing dietary Na levels with ionophore supplementation has also resulted in no beneficial VFA or gain responses *in vivo* (Karr et al., 1990; Muller et al., 1986).

Because of the high K:Na ratios of wheat forage, increasing salt levels of supplements may increase rumen and weight gain responses to monensin. Consistent supplement conversions (5 kg supplement/kg added gain) and increases in live weight gains (.23 kg·hd^{-1}·d^{-1}) have been reported when a

small package self-limiting monensin-containing supplement consisting of approximately 4% salt was fed to steers grazing wheat pasture (Horn et al., 1990, 1992; Beck et al., 1993). Thus, the objective of this study was to examine the ruminal effects of a monensin-containing energy supplement which contained either 0% or 5% salt when fed to steers grazing wheat pasture.

In previous studies aimed at developing a self-limiting monensin-containing energy supplement for growing cattle on wheat pasture, daily gains were consistently increased by about .23 $kg \cdot hd^{-1} \cdot d^{-1}$ and profits were increased by $15 to $31 per head, depending on feed cost and cattle profit potential (Beck et al., 1993; Horn et al., 1990, 1992). While some producers prefer self-fed supplements, others prefer hand feeding. Thus, another objective was to determine the effects of hand-feeding a monensin-containing energy supplement on an every other day basis to stocker cattle grazing wheat pasture.

CHAPTER 2

REVIEW OF LITERATURE

Mode of Action of Monensin

Ionophores are antibiotics widely used in both feedlot and grazing situations. Estimated annual sales of monensin are $70 million to feedlots alone with savings of $560 million in feed costs (Russell and Strobel, 1989). These polyether carboxylic acid compounds are capable of transporting cations across cellular membranes which effectively short circuits the cell's protonmotive force used to generate energy. This short circuiting greatly affects gram positive bacteria by robbing potential for energy production (conservation) thus inhibiting cellular growth (Lehninger et al., 1993). Most gram negative cells, however, have the ability to produce ATP using the electron transport chain located between the inner and outer membranes of the cell.

Bergen and Bates (1984) stated that ionophores exist at the membrane interface in an anionic form. In this form, the ionophore is able to pair with a metal cation such as Na or K, forming a lipophilic, cyclic complex able to diffuse through the lipid cell membrane. The structure destabilizes after encountering a polar environment on the opposite side

of the nonpolar membrane. This allows the ionophore to release the cation and return to the acyclic form and await a hydrogen ion for transport to the other side of the membrane. No cation transport across the membrane can occur unless the ionophore has bonded to a hydrogen ion or a metal cation. Ion transport is the basic method by which monensin affects ruminal bacteria. Some cells expel hydrogen ions either to conserve energy or to maintain intracellular pH or protonmotive force. Monensin binds to a hydrogen atom on the exterior of a cell membrane carrying it to the interior of the cell in exchange for a sodium ion (Bergen and Bates, 1984). Ion exchanges by ionophores across a cellular membrane are defined as antiporting. The cell pumps out this imported hydrogen ion to maintain intracellular pH thus consuming one ATP molecule.

Russell (1987) agreed with the above proposed ion transportation mechanism, but suggested that cation selectivity of monensin is a function of cation concentration gradients across the cellular membrane. Monensin has a much greater affinity for sodium than for potassium (Pressman, 1976), so a greater efflux of Na than K from the cell would be expected (Russell, 1987). However, relative concentration gradients across the cell wall must be considered to determine which ion is preferred by the ionophore. The K gradient can normally be 25 times greater

than the Na gradient; therefore, K efflux is more exergonic than Na. This K efflux coupled with H antiporting decreases intracellular pH and creates a H gradient across the membrane. The cell must pump out H ions at the expense of ATP to maintain protonmotive force and pH; however, the influx of H is too rapid to allow the gradient to be maintained. Once the H gradient is great enough, these intracellular H ions may be exchanged for extracellular Na using monensin as an antiporter. Since these ion effluxes are gradient driven by transmembrane Na and K concentrations, they theoretically could be altered by the addition of dietary cations. This could result in dietary Na stimulating and dietary K inhibiting the ruminal response to ionophores (Russell, 1987).

Both Bergen and Bates (1984) and Russell (1987) agreed that the principle mode of action of monensin is ion transport, but disagreed as to which cation is selected *in vivo*. Bergen and Bates (1984) stated that monensin has a greater affinity for Na cations and exchanges these cations for intracellular H ions. Russell (1987) agreed that monensin prefers Na ions when present in equal concentrations to K, but concluded that different Na and K gradients which exist across cellular membranes result in K transport by monensin being more exergonic than Na transport. Once the K gradient has been diminished by

monensin, Na transport and exchange for intracellular H is energetically possible (Russell, 1987). Additional research is needed to determine concentration gradients present in the rumen and the effects of these gradients on the mode of action of monensin.

Monensin Effects on the Animal

Animal Performance

Monensin has produced consistently increased weight gain by cattle consuming forage based diets. Horn et al. (1981) increased ($P < .01$) daily weight gains of heifers grazing wheat pasture by about .09 kg with supplements and an additional .08 kg ($P < .01$) with monensin. In these trials, the heifers (mean trial BW 233 kg) consumed about .9 kg/d of a corn or wheat-based supplement supplying about 100 $mg \cdot hd^{-1} \cdot d^{-1}$ of monensin. Similar increases in gain (.08 $kg \cdot hd^{-1} \cdot d^{-1}$; $P < .01$) were reported for cattle (mean trial BW 258 kg) grazing a wide range of good quality pastures when monensin was supplemented (200 or 400 mg/head) on an alternate day basis compared to cattle receiving no monensin (Muller et al., 1986). Muller et al. (1986) also reported no differences ($P > .05$) in ADG between monensin supplements offered as self-limiting or hand-fed supplements. Both feeding methods increased gains by .09 $kg \cdot hd^{-1} \cdot d^{-1}$ ($P < .01$)

over controls receiving no monensin. Potter et al. (1976) conducted three pasture trials and one greenchop trial in which good quality cool season grass-clover mix forages were consumed by steers. Mean BW of cattle was 288 kg and monensin was supplied at 0, 50, 100, 200, 300, or 400 $mg \cdot hd^{-1} \cdot d^{-1}$ in a .45 $kg \cdot hd^{-1} \cdot d^{-1}$ corn supplement fed twice daily. Doses of 100 to 300 $mg \cdot hd^{-1} \cdot d^{-1}$ resulted in .06 to .09 $kg \cdot hd^{-1} \cdot d^{-1}$ greater ($P < .05$) gains than supplements containing no monensin. Similar increases (.1 kg; $P < .005$) in daily gains from an intraruminal monensin device designed to release 100 mg/d were observed by Horn et al. (1988) with steer calves (mean trial BW 245 kg) grazing wheat pasture. Horn et al. (1990, 1992) observed increased gains (.24 and .22 $kg \cdot hd^{-1} \cdot d^{-1}$; $P < .05$) by steers (mean trial BW 284 and 325 kg respectively) on wheat pasture consuming a self-limited ground milo-based supplement containing 165 mg/kg of monensin compared to steers receiving no supplement. Supplements were converted to gain at 154 and 148 g/kg of supplement (6.48 and 6.75 lb supplement/lb of added gain). Similar gains and supplement conversions on wheat pasture have been reported by Beck et al. (1993) and Andrae et al. (1994) with comparable self-limiting monensin containing energy supplements. In a review of 40 cattle trials on pasture or in confinement, Potter et al. (1986) reported increased ($P < .05$) gains (.09 kg/d) from supplementation

with an additional .09 kg/d gain from monensin over a wide range of pasture qualities. Supplement conversions were also improved with monensin (5.0 vs 10.1 lb supplement/lb added gain) on growing pastures ranging from native range to wheat forage. Cattle in these trials were supplemented with 200 $mg \cdot hd^{-1} \cdot d^{-1}$ of monensin and had a mean trial BW of approximately 277 kg.

Oliver (1975) reported increased ($P < .05$) ADG of .166 kg/head from corn supplements versus monensin-containing corn supplements by steers grazing (291 kg mean trial BW) coastal bermudagrass pastures. Monensin-containing corn supplements increased ($P < .05$) ADG over cattle receiving no supplement from .24 to .32 kg. In a spring trial on wheat pasture, Grigsby (1984) fed .5 $kg \cdot hd^{-1} \cdot d^{-1}$ of an 85% steam flaked milo supplement with 0 or 160 $mg \cdot hd^{-1} \cdot d^{-1}$ of monensin to examine the effect of monensin on frothy bloat. Steers (mean BW 307 kg) fed monensin had higher ($P < .05$) gains (.34 $kg \cdot hd^{-1} \cdot d^{-1}$) compared to steers not receiving monensin and gained .28 $kg \cdot hd^{-1} \cdot d^{-1}$ more than unsupplemented steers. Grigsby (1984) stated that in a previous trial, during the winter months, monensin supplementation increased gains 26% when compared to no supplement and 26.4% when compared to supplements without monensin.

Ellis et al. (1983) reviewed thirteen pasture grazing trials on high-quality forages comparing a .45 or .91 kg

energy supplement supplying monensin (100 to 300 mg monensin·hd^{-1}·d^{-1}). Gain was increased approximately .10 kg/d with monensin supplementation when gains of cattle receiving no monensin were between .54 and .86 kg·hd^{-1}·d^{-1}. Responses to monensin diminished when gains of nonsupplemented cattle were above .86 kg·hd^{-1}·d^{-1}.

Lasalocid has produced comparable performance responses to those observed with monensin. Andersen and Horn (1987) observed increased weight gains (.11 kg/d) by heifers (266 kg mean trial BW) receiving 200 mg·hd^{-1}·d^{-1} of lasalocid versus heifers receiving 0 or 100 mg·hd^{-1}·d^{-1} of lasalocid. Spears and Harvey (1984)(steers mean BW 334 kg) and DelCurto et al. (1986) reported similar changes with cattle consuming forage and supplemented daily with 200 or 300 mg·hd^{-1}·d^{-1} of lasalocid.

Digestibility

Tanner et al. (1984) fed .45 kg·hd^{-1}·d^{-1} of ground milo as a carrier for monensin (100 or 200 mg) or lasalocid (100, 200, 400 mg) to heifers on ryegrass pasture. Early in the grazing season, DMD, NDFD and OMD of cattle receiving 100 mg·hd^{-1}·d^{-1} monensin were increased ($P < .05$) above controls. No effects on digestibility were observed later in the grazing season. Branine and Galyean (1990) reported

increased IVDMD using rumen fluid from steers supplemented with monensin on wheat pasture in mid-May. Extent of forage digestibility measured by *in situ* DM disappearance was equal at 48 h but monensin appeared to increase the rate of fiber degradation during the first 30 h of fermentation in early April. Rate and extent of digestion were similar in late April or mid-May. Ellis et al. (1983) reported a 4% average increase of OMD from monensin supplementation of cattle grazing bermudagrass and temperate grass pastures with decreasing effects as forage quality increased. Dry matter digestibility was unaffected with ionophore supplementation to cattle grazing wheat pasture (100 or 200 mg lasalocid/day; Andersen and Horn, 1987), sheep grazing range (33 to 165 mg monensin/kg supplement; Huston, 1990), sheep on a 56% alfalfa 31% corn diet (17 mg/d monensin to 30 kg lambs; Ricke et al., 1984) or with cattle consuming a 90% orchardgrass diet (11 to 33 ppm monensin; Dinius et al., 1976). In a review on the effects of ionophores on digestion (Spears, 1990), no difference was found in energy digestibility between diets containing monensin versus diets without this additive.

Fermentation

Short chain fatty acids supply approximately 70% of the total caloric requirements of cattle (Bergman, 1990). Feed

conversion and live weight gain responses are related to the proportion of each VFA and its efficiency of energy capture. Propionate production results in the retention of 3.08 MJ/mol of hexose fermented versus 1.75 and 2.20 MJ/mol hexose for acetate and butyrate, respectively (Sutton and Morant, 1978; as cited by Rowe, 1983). Thus, the production of propionate would result in more efficient use of energy. Richardson et al. (1976) examined *in vitro* and *in vivo* fermentation responses of high roughage and high concentrate diets to monensin. Adding monensin (5 ppm) to roughage diets *in vitro* decreased acetic ($P < .05$) and butyric ($P < .01$) acid production and increased production of propionate($P < .01$). An increase in propionate and decrease in butyrate production ($P < .05$) was observed at 1 ppm of monensin. Total VFA concentration did not change at any monensin level. Monensin (0, 50, or 200 $mg \cdot hd^{-1} \cdot d^{-1}$) decreased ($P < .05$) acetate and increased propionate ($P = .05$) proportions at the 200 mg level when tested *in vivo* with fistulated steers. No differences were observed in total VFA concentrations or proportions of butyric, valeric or isovaleric acids.

Horn et al. (1981) reported increases in propionate, isovalerate and pH, and decreases in acetate to propionate ratio and total VFA concentration four hours after monensin supplementation in steers grazing wheat pasture. The

acetate to propionate ratio remained lower ($P < .05$) and propionate proportion remained numerically higher than controls 24 h after supplementation. Methane production in the rumen was calculated to be numerically lower with monensin at both sampling times. Increases in propionate and isovalerate were also observed by Andersen and Horn (1987). Ricke et al. (1984) observed decrease in acetate to propionate ratio with ionophore inclusion ($P < .05$) at four and six h after feeding, but not at 2 h ($P > .05$). Propionate proportion was increased ($P < .05$) and butyrate and acetate proportions were decreased numerically at 6 h after supplementation. Total VFA concentrations were similar across sampling times. Rumen ammonia also was reduced 33% at 6 h by monensin ($P < .05$) and 17% across all time periods ($P > .05$).

Monensin increased ($P < .05$) ruminal pH of rumen fistulated steers grazing wheat pasture in early April and decreased ($P < .05$) butyrate proportion in early and late April (Branine and Galyean, 1990). Proportions of acetate, propionate and total VFA concentrations were not affected by grain or grain and monensin supplementation. A possible explanation for monensin not altering rumen VFA is that samples were collected at -4, -1, 2, 5, and 8 h post supplementation. Data were pooled over time and analyzed.

Propionate did exhibit a treatment X time interaction ($P < .07$) but treatment effects were not significant at any sampling time. Ruminal ammonia concentrations were variable over sampling times and dates.

Potter et al. (1976) noted increased ($P < .01$) propionate and decreased ($P < .01$) butyrate when supplements containing 50 to 400 mg monensin were fed to steers on introduced cool season pastures. Monensin (100 to 400 mg/d) decreased ($P < .01$) acetate proportions. Dinius et al. (1976) fed a diet of 90% orchardgrass hay containing 0, 11, 22 or 33 ppm of monensin. No differences ($P > .05$) were observed in total rumen VFA concentrations. Acetate proportions decreased and propionate proportions increased resulting in lower acetate to propionate ratios ($P < .01$) with monensin. No differences ($P > .05$) were observed in butyric, isobutyric, valerate, isovalerate, pH or ammonia levels. DelCurto et al. (1986) observed no reduction ($P > .10$) in acetate to propionate ratios but found butyrate to propionate ratios increased and pH decreased ($P < .05$) when .45 $kg \cdot hd^{-1} \cdot d^{-1}$ ground corn supplement containing lasalocid was fed to heifers consuming a mid-bloom alfalfa hay.

Van Maanen et al. (1978) fed a 70% alfalfa, 30% corn diet with and without 150 $mg \cdot hd^{-1} \cdot d^{-1}$ of monensin to steers (154 to 253 kg BW). Monensin increased propionate

production rate and pool size ($P < .05$). Proportion of propionate tended ($P > .05$) to be higher and butyrate was lower ($P < .05$) when fed monensin. Acetate proportions were not different ($P > .05$).

Homeostatic Control of Ruminal Sodium and Potassium

Sodium is the major cation of extracellular body fluid and aids in body fluid osmotic regulation (McDonald et al., 1988). Rate of absorption of sodium from the rumen is usually more rapid immediately following a meal when ruminal Na concentrations are high (Scott, 1974). Several researchers have also suggested that Na is absorbed against an electrochemical gradient, indicating an active transport mechanism (Gäbel and Martens, 1991); Aitken, 1976). Gäbel and Martens (1991) concluded from *in vitro* studies that ruminal Na ions could be exchanged for intracellular H ions of the ruminal epithelial cells. The intracellular Na ion is exchanged for a K ion from blood serum via a Na/K ATPase. Passive diffusion of Na from blood serum to the mucousal (lumen) side of the rumen epithelium was observed to occur in the reticular area (Gäbel and Martens, 1991).

Saliva from cattle contains about 126 mEq/L of Na, and cattle weighing from 434 to 450 kg consuming alfalfa forage will produce about 180 L of saliva per day (Church, 1988). Salivary production can potentially add 521 g of Na to the

rumen daily. The ions in saliva also serve to regulate and maintain ruminal osmotic pressure (Church, 1988). Dietary salt addition (5% DM) can increase rates of rumen dilution (Harvey et al., 1986). Faster flow may aid in regulating rumen Na levels by increasing Na cation flow from the rumen. Banks and Smith (1984) reported large diffusion of Na into the rumen from the blood plasma. The omasum also had a greater impact on Na absorption than the rumen.

Potassium is the primary intracellular cation of the body (McDonald et al., 1988), and is transported from the rumen to the bloodstream by passive diffusion (Aitken, 1976). Rate of K absorption from the rumen appears to be directly related to the rumen K concentration. Absorption rates of ruminal K increased from 6 to about 20 mEq/h as ruminal K concentration was increased from 40 to about 110 mEq/L (Scott, 1974). Evidence also suggests that increasing ruminal K concentration results in increased rates of Na absorption (Scott, 1974; Aitken, 1976).

Rumen Na and K concentrations are partially diet dependent. Rumen fluid from sheep fed hay had 66-95 and 34-71 mEq/L of Na and K, respectively, while rumen fluid of sheep fed a fresh grass diet had 25 and 125 mEq/L of Na and K (Sellers and Dobson, 1960). Rumen fluid from cattle on a 100% hay diet contained 108-120 and 23-44 mEq/L of Na and K (Emery et al., 1960). Blood serum levels of Na and K are

normally in the ranges of 140-145 and 3.5-5.5 mEq/L, respectively (McDonald et al., 1988).

All of these mechanisms serve to alter absorption and (or) ruminal dilution rates which ultimately result in the stabilization of ruminal and plasma Na and K concentrations.

Changes in Ionophore Response Due to Dietary Sodium or Potassium Levels

Sodium Levels

Increasing the sodium level of diets could potentiate the monensin response (Russell, 1987). Rumpler et al. (1986) added monensin or lasalocid (226 mg/d) and increased Na or K levels to 2.5% diet dry matter and of a 70% corn ration. With monensin, high Na concentration decreased ($P < .05$) while high K concentration failed to alter methane production. Sodium numerically decreased methane production when fed with lasalocid. *In vitro* propionate production increased ($P < .05$) with Na concentrations in cultures containing lasalocid or monensin (Schwingel et al., 1989). Mackie et al. (1984) observed decreased growth rates of bacteria with monensin and high salt levels *in vitro*. These salt levels were, however, greater than normal (70-170 mM) Na levels observed in the rumen. Numerical increases (5%) in DMI and ADG (7%) were observed when NaCl increased to

2.5% of intake in a corn silage diet carrying 200 ppm monensin (Karr et al., 1990). No differences were observed in total VFA, VFA proportions, pH or animal performance. Spears et al. (1990) fed salt (0, .05, .15 or .45% supplemental) and monensin (0 or 22 mg/kg) to growing steers on a corn silage diet. Monensin or a Na X monensin interaction did not affect ($P > .05$) steer performance. A sodium X monensin interaction was observed for proportions of acetate and propionate and the acetate to propionate ratios. Acetate to propionate ratios decreased at .05% and .15% dietary sodium but not at 0 or .45% Na (Spears et al., 1990). Muller et al. (1986) compared salt-limited (741 $g \cdot hd^{-1} \cdot d^{-1}$ salt) monensin supplements to hand-fed supplements (24 $g \cdot hd^{-1} \cdot d^{-1}$ salt) when grazing pastures ranging from native range to fescue. No differences were observed in daily weight gains between supplement types. Cattle gains averaged .667 $kg \cdot hd^{-1} \cdot d^{-1}$ for hand-fed supplements and .649 $kg \cdot hd^{-1} \cdot d^{-1}$ for self-fed groups.

Potassium Levels

Varying dietary cation concentrations with ionophores has resulted in differential responses. Feed efficiency and ADG decreased with increasing levels of dietary K in concentrate diets containing lasalocid (Gay et al., 1985). *In vitro* work with monensin and lasalocid showed increasing

microbial growth as media K concentration increased (Dawson and Boling, 1984, 1987). A 32-fold increase in monensin was required to inhibit *B. ruminocola* growth in media containing 23.3 mM K versus media containing 1.3 mM K (Dawson and Boling, 1987). Acetate to propionate ratios increased with increasing K concentrations in *in vitro* cultures with lasalocid(Schwingel et al., 1989). Total VFA production also decreased ($P < .05$) in both monensin and lasalocid treated cultures at high levels of K. Greene et al. (1986) infused K at 0, 7.6, or 31.6 g/d into the rumen of sheep consuming a high concentrate diet containing 20 g/kg monensin. Infusion of 7.6 g/d K increased ($P < .05$) acetate, decreased propionate and tended ($P > .05$) to increase the acetate to propionate ratio. The 31.6 g/d infusion did not differ ($P > .05$) from 0 g/d infusions. Funk et al. (1986) fed lambs a 65% concentrate diet containing lasalocid (20 mg/kg ration) and .9% or 2.5% K to determine if high dietary K inhibited the effects of lasalocid. No response to K was noted for ADG, feed efficiency or VFA production.

Sodium to Potassium Ratios

Dawson et al. (1983) compared the effect of Na to K levels (0 to 11; 7.7 to 3.3; 11 to 0) lasalocid activity *in vitro*. High levels of K depressed antimicrobial activity

while high Na activity increased activity. Spears and Harvey (1987) compared performance and ruminal VFAs of steers fed a high concentrate diet containing lasalocid (33 mg/kg) and different dietary Na to K ratios (.05% to .5%, .25% to .5%, .05% to 1.4%, and .25% to 1.4%). All Na and K levels tended to increase gain and feed efficiency above controls (.25% Na to .5% K and no lasalocid) except the high K and low Na treatment which were not different from controls ($P > .05$). Thus, at high K levels ionophore response was not inhibited with additional dietary Na inclusion. This suggests that the balance of potassium and sodium, as expressed by dietary Na to K ratios, could affect the antimicrobial activity of ionophores more than either cation viewed singularly.

Effect of High Dietary Salt Levels on Rumen Parameters

High levels of salt intake from self-limiting rations could affect variables such as rate of passage, forage digestibility, VFA production, fill and rumen osmolality. Each of these factors could impact animal performance independent of supplement effects.

Rate of Passage

Alteration of particulate or fluid fraction rate of passage could affect animal performance with increases in

particulate flow increasing forage and nutrient intake. Harvey et al. (1986) fed a high (226 g/d) and a low (23 g/d) level of salt in .36 kg of soybean meal to steers with *ad libitum* access to either fescue hay or corn silage diets. No differences ($P > .05$) in fine particulate matter passage rate or intake were observed for either forage or the soybean meal supplement. Zorrilla-Rios et al. (1990) observed no difference in particulate passage rate from the rumen of steers fed hay-based diets containing 5% salt.

More rapid fluid passage can increase the efficiency of rumen microbial protein synthesis and/or allow greater rumen escape of soluble nutrients (Owens and Goetsch, 1988). As rumen fluid passage rate increases, bacterial maintenance requirements decrease because bacteria associated with fine particles and fluid are flushed out of the rumen more rapidly and consequently use less energy for maintenance. This improvement in efficiency is also dependent upon particulate rates of passage, pH, osmotic pressure and other variables affecting rumen microbe maintenance costs (Owens and Goetsch, 1988).

Normally, high levels of dietary mineral salts increase fluid flow rates in concentrate diets but not in forage based diets (Merchen, 1988; Zorrilla-Rios et al. 1990). However, several studies with forages and high salt levels have shown increases in fluid passage rates. Riggs et al.

(1953) and Rogers et al. (1979) observed large increases in water intake with high salt consumption. Rogers et al. (1979), using steers fed a high roughage diet, observed an increase ($P < .05$) in rumen fluid dilution rate (10.65%/h vs 9.67%/h) when rumen infusions of solutions containing .5 and 1 kg of salt were compared to water infusion only. Harvey et al. (1986) fed steers 0 or 227 $g \cdot hd^{-1} \cdot d^{-1}$ salt with fescue hay or corn silage and observed greater ($P < .05$) fluid dilution rates with the high salt level. The magnitude of change for corn silage dilution rates was larger than for fescue hay (4.1% vs. 1.3% respectively) suggesting that diet moisture content may affect how much dilution rate is impacted by dietary salt levels. Brandyberry et al. (1991) observed a greater ($P < .05$) fluid dilution rate for animals consuming a salt-limiting supplement during summer months on native range. Sheep fed a pelleted diet of 40% grass and 60% concentrate at hourly intervals had greater ($P < .05$) fluid dilution rates (3.6%/h, 5.3%/h and 6.4%/h) when fed high levels of salts (0%, 5.7%, and 11.4% diet DM); Thomson et al., 1978). When the animals were fed twice daily, the dilution rates tended to increase but were not significant. Bergen (1972) infused NaCl and sodium acetate into the rumen of two sheep and measured flow rates with polyethylene glycol (PEG). These sheep were on a high roughage diet, and were withheld from feed for 10 h prior to sampling. No

difference ($P < .05$) was observed in fluid passage rate although rates of passage were numerically greater than controls.

These trials indicate that the rumen fluid dilution rate of animals on forage diets may be altered by the addition of high levels of dietary salt. This increased rate of passage which may result in increased rumen microbial efficiency, but not enough data exists to determine if performance is improved from this increased efficiency.

Digestibility

Cardon (1953) conducted *in vivo* digestibility trials examining the effects of high salt intake on cellulose digestion. Three Hereford cows were fed alfalfa hay mixed with either 0 or .82 kg salt or were drenched with .91 kg salt. Observed cellulose digestibility was 55.0%, 55.1%, and 56.5%, for the respective salt levels, with no differences ($P > .05$) observed between treatments. A 12 h incubation *in vitro* trial showed very similar results leading Cardon (1953) to conclude that daily consumption of up to .91 kg of salt by cattle does not negatively impact fiber digestibility. Nelson et al. (1955) found comparable results with a 77% prairie hay, 16% cottonseed meal and 6%

salt ration. Organic matter digestibility of the ration did not differ ($P > .05$) from rations containing 0% added salt when fed to steers, but was lower ($P < .01$; 69.2% vs. 66.8%) when fed to wethers. Riggs et al. (1953) observed a 5% increase in crude fiber digestibility with a high salt diet. Brandyberry et al. (1991) also observed increased ($P < .05$) total organic matter digestibility with salt-limiting supplements. The animals in this trial grazed native range and were individually fed supplements containing 19.5% salt (.23 kg/d) in the summer and 29.6% salt (.40 kg/d) in the winter. The authors stated that digestibility increases could be a result of a sodium deficiency on native range, but was more likely a result of forage selection differences between treatment groups since NDF digestibility was not different between treatments.

Fill

Fluid and particulate rumen fill of steers consuming roughage diets with high salt supplements did not differ ($P < .05$) from steers on low salt supplements (Brandyberry et al. 1991; Zorrilla-Rios et al. 1990). Rogers et al. (1979) observed increases ($P < .05$) in rumen fluid volume (57.6 vs 66.1 L) with salt addition to steers on high roughage diets. This increase in fluid fill could result in the dilution of

total VFA concentrations in the rumen without affecting the actual number of VFA. This decrease in total VFA concentration has been observed (Rogers et al., 1979). However, due to the limited number of studies addressing this topic, and the lack of agreement between them more research is warranted in this area.

VFA Production and Proportions

Normally on high concentrate diets, the inclusion of high salt-levels (5% diet DM) results in increases of molar proportions of acetate and decreases in proportions of propionate (Merchen, 1988). Similar results were found by Thomson et al.(1978) with sheep fed a 40% grass and 60% concentrate diet and by Rogers et al. (1979) with steers fed a high-concentrate finishing diet. However, there appear to be interactions between forage and concentrate diets. Rogers et al. (1979) found no differences ($P > .05$) in proportions of acetate, propionate or acetate to propionate ratios with steers fed a high-salt, high-roughage diet; but a decrease ($P < .05$) in butyrate proportion was observed. No effect ($P > .05$) of salt on acetate to propionate ratio or molar proportions of propionate, butyrate or isobutyrate was observed when steers were fed high-salt levels on either fescue hay or corn silage based diets, but decreases ($P < .05$) in valerate and isovalerate proportions were shown.

Acetate increased ($P < .05$) early in the trial, but this increase was not significant across all sampling dates (Harvey et al., 1986). High-salt supplementation of steers on native range in Kansas resulted in decreases ($P < .05$) in the molar proportion of acetate and increases ($P < .05$) in propionate proportions resulting in lower acetate to propionate ratios than steers fed low-salt supplements (Brandyberry et al., 1990). Differences in acetate and propionate responses to high-salt additions appear to be more prevalent in high-concentrate diets, leading Rogers et al. (1979) to conclude that the alteration of acetate to propionate ratio depends upon the potential of the initial ratio for change. Animals with normally high ratios of acetate to propionate probably will not be further elevated.

Rumen Osmolality and Feed Intake

Rumen osmolality appears to limit voluntary feed intake to some extent. Owens and Goetsch (1988) report that normal ruminal fermentation occurs between 260 and 340 mOsm/kg. Feed intake can increase the osmolality of rumen fluid which may be sensed in the wall of the reticulorumen and limit intake in sheep (Carter and Grovum, 1990a).

Restricting intake of self-limited supplements using salt as a limiting agent is a common practice. Because salt causes rumen osmolality to increase, its supplement

limiting effects may not be solely due to palatability effects. Studies examining effects of rumen fluid osmolality on intake typically bypass palatability effects by introducing salt through the rumen cannula. A negative linear relationship between voluntary feed intake and rumen fluid tonicity over the range of 250 to 400 mOsm/kg was observed in sheep by Ternouth (1967, as cited by Carter and Grovum 1990a)and Phillip et al.(1981, as cited by Carter and Grovum 1990a) after rumen infusions of salt solutions and hypertonic extracts of fresh and ensiled whole corn plants. Bergen (1972) also observed this inverse relationship, but concluded that rumen osmolality must exceed 400 mOsm/kg for noticeable decreases in intake to be observed. Rumen osmolalities in controls rose to 270 mOsm/kg by two hours after feeding while osmolalities of the salt infused sheep rose to about 512 mOsm/kg by one hour after feeding. Feed intakes of the salt infused sheep were about 305 g/day while intakes of the control group were about 640 g/day. Horn et al.(1979) fed rumen cannulated steers ground, ensiled high-moisture diets with or without various buffers. Rumen tonicity of all steers was increased 50% by one hour post-feeding. All rumen osmolalities were within normal ranges within eight hours post-feeding with the greatest decline in the one to four hour post-feeding period. Carter and Grovum (1990b) showed that food intake was only affected for about

four hours after salt loading, indicating that osmolality probably has only a short term influence on intake.

Salt addition resulted in a linear intake depression ($P < .05$) until water was introduced to sheep (Carter and Grovum, 1990b). After water was made available, feed and water intake were higher ($P < .05$) in salt infused versus control animals. The addition of 50g salt to the rumen of sheep increased osmolality by 249 mOsmol/kg within ten minutes compared to an increase of only 33 mOsmol/kg in the controls. Water consumption decreased osmolality by 146 mOsmol/kg and 29 mOsmol/kg in salt infused and control group, respectively. This indicates that increasing rumen fluid tonicity by salt loading decreases intake while water consumption decreases tonicity allowing intake of normal feed levels (Carter and Grovum, 1990b). These studies were conducted over only a 90 minute time period and long term effects of ruminal fluid osmolality on intake were not studied.

Self-limiting supplements with high salt levels (19.5% and 29.6%) did not affect ($P < .05$) forage intake when compared to steers consuming a similar hand-fed, low-salt (0%) supplement (Brandyberry et al., 1991). In contrast, dry matter intake was decreased ($P < .05$) as a result of adding one kg of salt to a high roughage diet (Rogers et al., 1979). However, salt intake (.23 and .40 kg/steer/day)

was much lower in the study of Brandyberry et al. (1991), and may not have been enough to affect forage intake. Total forage intake in the trial of Brandyberry et al. (1991) was also low (1.68% BW) so intake may only be affected where animals must graze for long time periods.

Rumen tonicity appears to affect intake to some degree, but this effect lasts only for short time periods. Therefore, high-salt containing supplements are not limited entirely from palatability effects; however, self-limiting supplementation does not appear to affect forage intake.

Summary of Literature Review

Monensin inhibits microbial growth through the exchange of K or Na cations for H ions across the cellular membrane of gram-positive bacteria. Selection of cations by monensin is dependent upon Na and K concentration gradients across this cellular membrane. Daily weight gains of cattle grazing good to high quality forage and supplemented with monensin dosages greater than 100 $mg \cdot hd^{-1} \cdot d^{-1}$ are consistently improved by approximately .09 $kg \cdot hd^{-1} \cdot d^{-1}$. Energy, DM, and OM digestibility are apparently unaffected by including lasalocid or monensin in high forage diets. The proportions of VFAs are typically altered with monensin addition. Propionate proportions are typically increased and (or) acetate proportions are decreased which results in

a decreased acetate to propionate ratio. Total VFA concentrations usually are unaffected by monensin addition, but may be occasionally decreased.

Sodium absorption in the rumen may take place against a concentration gradient which suggests that it is absorbed by active transport. Ruminal K absorption occurs by passive diffusion and increases as ruminal K concentration increases. There have also been reports of increased Na absorption with additional ruminal K concentrations which may aid regulation of ruminal Na and K concentrations.

If optimal Na:K ratios could be defined, Na supplementation in high K diets to balance this ratio and increase ionophore antimicrobial activity could increase animal performance. Another potential area of concern is the effect of the anion associated with the Na and K added in the trials. Chloride ions added in conjunction with Na and K could be masking actual effects of the cations. Rogers and Davis (1982) supplemented 5% sodium bicarbonate and 33 ppm monensin to steers on a 50% corn silage, 50% concentrate diet. These steers exhibited lower ($P < .10$) propionate proportions when monensin and sodium bicarbonate were fed in combination which is opposite of normal NaCl effects.

Most trials examining the effects of cations on ionophore response have been conducted *in vitro*. Future *in*

vitro trials should focus on physiologically realistic Na, K and ionophore concentrations. More *in vivo* trials are needed to determine ionophore responses from given Na:K dietary ratios. Because of the affinity of lasalocid for K, much research has been conducted with this ionophore and cation. Additional *in vivo* studies examining the effect of monensin with varying dietary Na and K levels are needed.

Dietary salt levels of greater than 5% increased rumen fluid dilution rates of forage fed cattle. This increase in fluid flow might result in increased efficiency of rumen microbial growth or allow greater rumen escape of soluble nutrients. However, there is little performance data to evaluate actual effects on gains. Few effects of high salt level on OM digestibility of forage were observed with cattle. Different effects of salt intake on rumen fill have been reported, so more research in this area is warranted. The proportion of rumen VFAs may be altered with high-salt supplementation to high forage diets, but this appears to be dependent upon initial acetate to propionate ratios. If these ratios were already high before high levels of salt were added, they probably will not be further elevated by salt addition. Rumen osmolality greater than 350 mOsm/kg appear to depress intake for short time periods. Thus, osmolality and palatability may limit high-salt supplements.

However, forage intake does not appear to be affected by high-salt supplements.

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CHAPTER 3

EFFECTS OF SALT LEVEL IN A MONENSIN-CONTAINING ENERGY SUPPLEMENT ON IONOPHORE POTENTIATION AND RUMEN FERMENTATION OF STEERS GRAZING WHEAT PASTURE

J.G. Andrae, G.W. Horn and D.S. Buchanan

ABSTRACT

Nine rumen canulated steers were used in two wheat pasture grazing seasons to evaluate the effects of a monensin-containing energy supplement and level of salt inclusion on rumen fermentation. Within each year, steers were randomly assigned to one of three treatments: 1) no supplement, 2) a monensin-containing energy supplement with a low level of salt (0-.5%) or 3) a monensin-containing energy supplement with a greater salt level (4-5%). Both supplement and salt level had no effect ($P > .20$) on rumen pH in either year. Osmolality was not affected ($P > .17$) by supplement or salt level in Year 1 but was affected differently by supplement and sampling time ($P < .01$) in Year 2. Supplementation decreased acetate ($P < .05$) and increased propionate proportions ($P < .10$) resulting in a decreased acetate to propionate ratio ($P < .05$) in both years. High salt supplementation did not affect acetate to propionate ratios ($P > .40$ and .18) or acetate ($P > .44$),

but propionate tended to be greater with high salt levels (P = .07) in Year 2. Butyrate proportions were not affected by supplement or salt (P > .46) in Year 1, but butyrate responses varied with sampling time and supplement (P < .10) in Year 2. Valerate and iso-acid proportions were not affected by treatment (P > .15) in Year 1, but in Year 2 isobutyrate, valerate and isovalerate (mol/100 mol) were decreased (P < .08) with supplementation and valerate was further decreased (P = .06) with additional salt. These data indicate that a monensin-containing energy supplement changes rumen parameters in a beneficial manner. However, increased supplemental salt levels do not appear to enhance these effects.

(Key words: Monensin, Energy, Supplementation, Pasture, Cattle, Salt)

Introduction

Monensin facilitates cation (Na and K) transfer across cellular membranes thereby preventing the growth of gram positive bacteria (Bergen and Bates, 1984; Russell, 1987). Rumen concentrations of these cations may determine which is selected by monensin with typical rumen concentrations favoring K over Na transport (Russell, 1987). High dietary K levels appear to inhibit the antimicrobial effects of monensin (Dawson and Boling, 1987). Increasing dietary Na

levels "stimulate the rumen environment" (Russell, 1987) and appear to prevent the K inhibition of ionophore effects (Dawson et al., 1983). These responses have been observed consistently *in vitro,* but *in vivo* responses have been both beneficial (Rumpler et al., 1986; Spears and Harvey, 1987; Spears et al., 1990) and nonexistent (Muller et al., 1986; Karr et al., 1990).

Wheat forage often contains K levels that exceed 4% of DM (Mayland et al., 1976; Stewart et al., 1981). These high K levels might have the potential to inhibit ionophore response. Steers consuming a 4% salt monensin-containing energy supplement while grazing wheat pasture have gained .23 $kg \cdot hd^{-1} \cdot d^{-1}$ more than unsupplemented steers and had supplement conversions of 4.5 to 6.75 kg supplement/kg additional gain (Horn et al., 1990, 1992; Beck et al., 1993). Previously, supplementation of a similar 1% salt supplement increased gains .07 to .12 $kg \cdot hd^{-1} \cdot d^{-1}$ with supplement conversions ranging from 7.3 to 11.4. (Vogel et al., 1989; Smith et al., 1990). Because of the greater daily gain responses with increased supplemental salt concentrations and the possible relationship between dietary cation concentrations and ionophore effectiveness, the objective of this study was to examine the ruminal effects of a monensin-containing energy supplement with either low or additional salt levels.

Materials and Methods

Year 1. Nine mature steers (775 kg) fitted with permanent large rumen canulas (10 cm i.d.) were placed on a single wheat pasture (*Triticum aestivum* variety Karl) on March 10, 1993 and randomly allotted to one of three treatments on March 16, 1993 (d 0). Treatments consisted of 1) no supplement, 2) 1.36 $kg \cdot hd^{-1} \cdot d^{-1}$ of a monensin-containing energy supplement with .5% salt in pellet form or 3) a monensin-containing energy supplement with 4% salt in meal form. Ingredient composition of the supplements is shown in Table 1. No other salt or mineral supplements were available to the steers throughout the trial, and monensin content of supplements was verified using colorimetric analysis (Golab et al., 1973). All steers were gathered from pasture daily from day 0 to day 11 at approximately 0800 and individually offered their respective supplement in a barn equipped with individual feeding stalls located adjacent to the pasture. If the supplement was not entirely consumed, it was placed directly in the rumen through the fistula. On d 11, fluid samples were obtained through the rumen fistula with a 250 ml beaker at two, four and six hours following supplementation. Steers were held in drylot pens without access to feed or water throughout this

sampling period to minimize sample variation and prevent the possible dilution of ruminal contents.

Ruminal fluid was strained through four layers of cheesecloth and pH was immediately measured using a pH meter and a glass electrode. Microbial activity of samples was stopped by acidifying 200 ml aliquots with four ml of 20% sulfuric acid (v/v). Samples were centrifuged at 10,000 x *g* for 10 min to remove debris. Supernatant (20 ml) was decanted for ammonia analysis using magnesium oxide distillation (AOAC, 1975) as modified by Andersen and Horn (1987). Several aliquots (5 ml) were frozen for osmolality, Na and K concentration, and VFA analyses.

Rumen fluid aliquots for Na and K were later thawed and centrifuged at 20,000 x *g* for 20 min. Supernatant was decanted and diluted in ultrapure water for analysis of rumen soluble Na and K using a Perkin-Elmer Model 403 atomic absorption spectrophotometer (Perkin-Elmer, Norwalk, CT). Osmolality was determined using the freezing point depression technique with an Osmette precision osmometer Model 2007 (Precision System Inc., Sudbury, MA). Aliquots for VFA analysis were acidified with one ml of 25% metaphosphoric acid (w/v). After protein precipitation, samples were centrifuged at 25,000 x *g* for 20 min, and supernatant was frozen. Later, samples were thawed and centrifuged at 20,000 x *g* for 20 min. One hundred µL of

supernatant with 900 µL of water diluent containing 2-Ethylbutyric acid (90 µL/L) as an internal standard were injected into a gas chromatograph (Perkin-Elmer 9000 Model Series, Norwalk, CN) for measurement of VFA concentrations. A Megabore DB-FFAP liquid phase column (30m X .53mm) was used with 8 ml/min of helium as the carrier gas. Column oven temperature was programmed at 110°C for .2 min then was increased at 15°C/min to 145°C and held for .5 min. This temperature was then elevated at 45°C/min to 235°C following each sample to clean the column of impurities. Injection and flame ionization detector temperature were maintained at a constant 250°C.

Forage quality samples were handclipped at four pasture locations on the day of rumen sampling, dried in a forced-air oven at 58°C and ground through a Wiley mill (Standard Model 3, Arthur H. Thomas Co., Philadelphia, PA) to pass a 2mm screen. Forage CP was determined using the Kjeldahl procedure and multiplying N X 6.25. Atomic absorption spectrophotometry was used to determine Na and K content of the forage. Plant tissue was digested and analyzed using a dry ashing method (Anonymous, 1982). In this procedure two grams of forage were ashed at 500°C for five hours. The ash was then dissolved in 10 ml of 20% HCl and boiled for 15 min. This solution was then filtered through Whatman #41

filter paper into glassware which had been previously soaked for 48 h in a chromium trioxide and sulfuric acid solution and rinsed with ultrapure water.

Year 2. Procedures for Year 2 differed from Year 1 in the following respects. Treatments were: 1) no supplement, 2) supplementation of 1.36 kg ground corn containing 299 mg monensin, and 3) supplementation of 1.36 kg ground corn with 299 mg monensin and an additional 75 g salt. The additional 75 $g \cdot hd^{-1} \cdot d^{-1}$ salt is similar to the salt intake of steers consuming 1.82 $kg \cdot hd^{-1} \cdot d^{-1}$ of the 4% salt supplement fed by Beck et al. (1993). Supplementation began on March 21, 1994 (d 0) after steers had grazed wheat pasture for several weeks. All supplements were delivered through the rumen fistula for the entire trial to prevent refusal and insure uniform intakes. One steer was slightly bloated on days 8 through 14, so poloxalene was administered with the supplement on these days. On day 17, animals were gathered from the wheat pasture at 0730 for supplementation. Steers were held in drylot and collection of ruminal fluid samples occurred at 2, 4 and 6 hours post-supplementation. Ruminal fluid was treated identically to Year 1 samples except fluid samples for VFA analysis were deproteinated using solid metaphosphoric acid (.05 g per 5 ml aliquot). Tubes were inverted several times to insure complete dissolving and mixing of the acid.

Statistical Analysis. The data were analyzed by least squares ANOVA using the GLM procedure of SAS (1985). Both trials were analyzed as a split-plot experimental design with individual steer as the experimental unit and multiple measurements on each steer as the sampling unit. The model used for analysis included treatment (supplement), steer within treatment, sampling time and the time by treatment interaction. The error term for treatment was animal within treatment, and the error term for time and treatment x time interaction was the residual mean square. Treatment means were compared with orthogonal contrasts as follows: 1) control versus mean of the two supplement treatments and 2) low salt versus additional salt treatments. When the treatment x time interaction was significant ($P < .15$), interaction least squares means were calculated and compared at each point in time with least significant differences (Steele and Torrie, 1980).

Results and Discussion

Main effects of supplement for Years 1 and 2 are presented in Tables 2 and 3, respectively. Where a treatment X sampling time interaction was significant ($P < .20$), treatment means are displayed graphically over sampling times in various figures.

Forage Analysis. Forage analysis from both years revealed lower K levels than are normally observed with growing wheat pastures (Table 4). Stewart et al. (1981) and Mayland et al. (1976) reported winter wheat K concentrations were commonly greater than 4% DM and K levels occasionally exceeded forage nitrogen levels. Potassium levels of wheat forage typically decrease during late fall and then increase rapidly in the spring. This increase in the spring is followed by a gradual decrease in potassium levels as the plants mature (Stewart et al., 1981). Because wheat forage was actively growing, rumen sampling may have occured late in the plant growth curve when forage K levels had begun to decline. The low forage K content could help to explain the lack of response to additional supplemental salt as forage K levels may have been too low to inhibit ionophore antimicrobial effects as previously observed *in vitro* (Dawson and Boling, 1987).

pH. Rumen pH was not affected by supplement (P = .55 and .20) or salt level (P = .53 and .63) in both experiments. Rumen pH in Year 1 was lower than would be expected from animals consuming a forage diet. However, similar rumen pHs have been observed in steers grazing wheat pasture (Branine and Galyean, 1990). Monensin supplementation increased rumen pH of these steers in early April but not in late April or mid-May (Branine and Galyean,

1990). Andersen and Horn (1987) reported no differences ($P > .05$) in rumen pH of cattle grazing wheat pasture when lasalocid was included in an energy supplement. Horn et al. (1981) reported ranges in rumen pH from 6.22 to 6.91 four hours after feeding of .23 $kg \cdot hd^{-1} d^{-1}$ of a ground corn based supplement containing 0 or 200 mg monensin with steers grazing wheat pasture. Inclusion of monensin increased ($P < .01$) rumen pH in rumen cannulated steers, but no pH differences ($P > .05$) were reported in steers with rumen fluid aspirated through a stomach tube.

Ammonia. Rumen ammonia concentrations were not affected ($P > .58$) by treatment in Year 1, but both supplement ($P < .01$) and salt ($P < .05$) decreased rumen ammonia concentrations in Year 2. Rumen ammonia concentrations in Year 2 were lower than in Year 1 and in previous wheat pasture grazing trials (Horn et al., 1981). Dinius et al. (1976) observed decreased ammonia concentrations with addition of 11 to 33 ppm monensin to a 90% orchardgrass diet, but because of large animal to animal variation within treatments, this decrease was not significant ($P > .10$). Faulkner et al. (1985) concluded that monensin inclusion of 6 to 36 ppm in a high fiber diet decreased either rumen proteolysis or bacterial protein synthesis. Branine and Galyean (1990) observed decreased rumen ammonia levels but speculated the decrease was a result of increased bacterial

protein sythesis from supplemental energy utilization. Reasons for decreased rumen ammonia concentrations with additional salt supplementation in Year 2 are also unclear. Harvey et al. (1986) observed decreased ($P < .05$) rumen ammonia in steers consuming corn silage or hay diets with high dietary salt levels (approx 190 g salt/d). In contrast, Brandyberry et al. (1990) observed no changes ($P > .50$) in rumen ammonia concentrations when cattle grazing native range consumed supplemental salt levels ranging from .23 to .40 kg/d. Rumen fluid dilution rate was increased ($P < .05$) with dietary salt level in both trials (Harvey et al., 1986; Brandyberry et al., 1990). Increased rumen fluid dilution rates have also been reported with greater levels of dietary salt in cattle (4% of total diet, Cheng et al., 1979; .5 to 1 kg/d, Rogers et al., 1979) and in sheep (150 g/d, Hensley, 1975; 5.7 and 11.4% of total diet, Thomson et al., 1978). However, moisture content of the basal diet appears to have an impact on the magnitude that dilution rates are affected. Brandyberry et al. (1990) observed increased ($P < .05$) fluid dilution rates in summer with salt limiting supplements but not in winter months ($P > .68$) when bluestem range was dormant. Harvey et al. (1986) observed a larger increase in fluid dilution rates with salt addition for corn silage versus fescue hay diets. Because wheat forage in Year 2 had 29.7% DM, fluid dilution rate may have

increased with additional salt supplementation resulting in decreased rumen ammonia levels. Brandyberry et al. (1990) and Harvey et al. (1986) did not include monensin in their supplements which has previously been shown to reduce turnover rates of liquid in the rumen (Lemenager et al., 1978).

Osmolality, Na and K levels. Supplementation in Year 1 numerically increased ($P > .17$) osmolality by 9.6%, but additional supplemental salt (55 $g \cdot hd^{-1} \cdot d^{-1}$) did not further increase ($P > .89$) osmolality of rumen fluid in Year 1. In Year 2, a treatment X sampling time interaction was observed ($P < .01$) for rumen osmolality (Figure 1). Osmolality for the supplement containing additional salt declined more rapidly than other treatments. This interaction may be related to rumen soluble Na levels (Figure 2) which also exhibited a treatment X sampling time interaction ($P < .01$). Rumen soluble Na levels decreased over sampling times in steers fed the additional salt while Na concentrations of other treatments increased. These responses may also be explained with increased rumen fluid dilution rate for steers supplemented with additional salt.

In Year 1, ruminal Na concentrations were increased ($P < .01$) and ruminal K concentrations were decreased ($P < .02$) with supplementation. Dietary salt addition did not further affect rumen soluble Na or K levels ($P = .20$ and .19,

respectively) in Year 1. Karr et al. (1990) observed no differences in ruminal K levels ($P > .10$) with increased dietary Na levels. Rumen soluble Na levels were not changed with increased dietary Na levels (Spears and Harvey, 1987) which the authors explained from large amounts of Na addition to the rumen from saliva. Saliva effects may also explain response differences of rumen soluble Na and K concentrations between years in our study, because supplements were fed in Year 1 and administered through the fistula in Year 2. A treatment X sampling time interaction ($P < .03$) was observed for soluble rumen K levels (Figure 3) in Year 2. Rumen K concentrations were greater in steers fed the ground corn with no additional salt than for other treatments. Rumen soluble K concentrations for steers supplemented with additional salt appeared to decline more rapidly with time than other treatments. This is consistent with data of Spears et al. (1990) in which rumen soluble K and Na were inversely related. Scott (1974) stated that absorption of K in the rumen occurs passively and that absorption rates increase with greater rumen K concentrations. The ruminal absorption rate of Na may also increase with greater ruminal K levels (Scott, 1974; Aitken, 1976). Supplementation increased ruminal Na:K ratios in Year 1 ($P < .01$) and tended to increase ratios in Year 2 (P

< .12). Additional supplemental salt also increased this ratio in both years (P < .06 and .01).

VFA. A treatment X sampling time interaction (P < .10) was observed for total VFA concentrations in Year 1 (Figure 4). Total VFA concentrations declined (P < .05) over time for both control steers and steers fed the low salt supplement but did not change for steers fed supplements containing additional salt (P > .05) in Year 1. Four hours after supplementation, monensin has decreased (P < .01) and not affected (P > .05) total ruminal VFA concentrations of cattle grazing wheat pasture (Horn et al., 1981). However, reasons for increased VFA concentrations with supplements containing low salt levels and monensin are unclear. Total VFA concentrations were not affected (P > .33) by treatment in Year 2. Similarly, Karr et al. (1990) reported that monensin supplementation with increased salt levels in the diet did not change (P > .10) total VFA concentrations. Total VFA were also not affected by ionophore addition in cattle grazing wheat forage (Branine and Galyean, 1990; Andersen and Horn, 1987) and good to high quality cool season pastures (Potter et al., 1976).

Acetate (mol/100 mol) was lower (P < .05) for supplemented cattle in both years, but no effect of supplemental salt level (P > .44) was observed in either

year. Propionate (mol/100 mol) increased in Year 1 (P = .09) and Year 2 ($P < .01$) with supplementation. Salt also tended (P = .07) to increase propionate levels (mol/100mol) in Year 2. Supplementation decreased ($P < .05$) the acetate to propionate ratio in both years. Mean acetate to propionate ratios with additional salt supplements were numerically lower than ratios with low salt supplements at all sampling times in both years; however, this decrease was not significant ($P > .18$) in either year.

Monensin supplementation to cattle on high forage diets often increases propionate proportions and decreases acetate proportions and acetate to propionate ratios (Richardson et al., 1976; Horn et al., 1981; Branine and Galyean, 1990). This allows more energetically efficient fermentation and can improve animal performance (Rowe, 1983). Increased levels of supplemental salt did not potentiate these responses in Year 1, but tended (P = .07) to increase propionate (Table 3) in Year 2 at the apparent expense of butyrate (Figure 5).

Russell (1987) developed a model for the transmembrane cation transport that takes place in the rumen with ionophores. Within this model, ionophore activity is affected by the relative concentrations of extracellular and intracellular Na and K concentrations. High ruminal (extracellular) K levels could inhibit ionophore transport

of cations while increasing ruminal Na levels may offset this inhibition. In agreement with this model, microbial growth was increased in cultures containing high K levels and ionophores (Dawson and Boling, 1984, 1987) suggesting a depression of the effectiveness of ionophores in the presence of high K concentrations. Greater rates of propionate production (Schwingel et al., 1989) and decreased microbial growth rates (Dawson et al., 1983) were observed with additional Na addition *in vitro* which also suggests increased dietary Na concentrations help to improve ionophore effectiveness in the presence of high dietary K levels.

In vivo results, however, have not been consistent. Funk et al. (1986) observed no differences in performance or VFA composition of sheep consuming increased levels of K with lasalocid. Karr et al. (1990) observed no dietary Na level effects on rumen VFA or weight gains of steers consuming a corn silage diet containing monensin. In contrast, Na supplementation with ionophores has resulted in beneficial responses. Decreased methane production was observed in steers fed increased dietary Na levels and monensin (Rumpler et al., 1986). Spears et al. (1990) observed decreased acetate to propionate ratios in steers receiving 22 mg/kg monensin and .05% or .15% dietary salt, but dietary salt levels of 0% or .45% had acetate to

propionate ratios equal to those of steers receiving no monensin. Because acetate to propionate ratios of salt supplemented animals in our trial were numerically lower at all sampling times in our trial, the small number of animals per treatment may have prevented significant changes in acetate to propionate ratios.

No difference in butyrate (mol/100 mol) was observed in Year 1 from supplementation ($P < .50$) or salt level ($P < .46$). Decreases in butyrate proportions have been previously observed with both monensin (Horn et al., 1981) and lasalocid supplementation (Spears and Harvey, 1984, 1987). In contrast, DelCurto et al. (1984) observed increased ($P < .01$) butyrate to propionate ratios in heifers supplemented daily with .45 kg/hd ground corn containing 200 mg lasalocid. Richardson et al. (1976) observed no butyrate (mol/100 mol) changes with monensin addition *in vivo*. In Year 2, a treatment X sampling time interaction ($P < .12$) was denoted in that butyrate (mol/100 mol) declined ($P < .05$) in the 4 to 6 h sampling period for unsupplemented but not for supplemented steers. Butyrate was also lower ($P < .05$) across sampling times for animals fed additional salt (Figure 5). Decreased butyrate proportions with additional salt supplementation appear to correspond with increased propionate proportions, suggesting increased ionophore effects. This response is, however, questionable because

the observed forage K levels were lower than expected and may not have inhibited ionophore response.

Isobutyrate, valerate and isovalerate (mol/100mol) were not affected in Year 1 by supplementation ($P > .43$) or salt ($P > .17$) treatments. In Year 2, supplementation decreased ($P < .05$) isobutyrate and valerate (mol/100mol) and tended to decrease ($P = .07$) isovalerate (mol/100 mol). Steers supplemented with additional salt also tended ($P = .06$) to have lower valerate (mol/100 mol) than steers receiving low salt supplements. No changes in isobutyric, valeric or isovaleric acids were observed when monensin was supplemented to cattle receiving 90% orchardgrass diets (Dinius et al., 1976). Previously, monensin and lasalocid supplementation changed ($P < .10$) ruminal isovalerate proportions on wheat pasture, but the direction of these changes do not agree with our observations (Horn et al.,1981; Andersen and Horn, 1987). Isobutyrate concentrations were increased ($P < .10$) with increasing dietary Na concentrations and lasalocid (Spears and Harvey, 1987). Decreased ($P < .10$) valerate proportions were also observed in steers supplemented with 200 or 300 mg/d lasalocid and grazing cool season pastures (Spears and Harvey, 1984).

Implications

Supplementation of monensin-containing energy supplements resulted in favorable ruminal responses which include decreased acetate to propionate ratios in both years of the study. This decrease in acetate to propionate ratio should result in improved performance of growing ruminants fed monensin-containing energy supplements. However, additional salt supplementation did not appear to further improve ruminal effects of a monensin-containing energy supplement with cattle grazing wheat pasture containing less than 2% K concentration.

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Table 1. Ingredient composition of supplements. (% as-fed basis)

Supplement	Year 1	
	Monensin Low Salt	Monensin Additional Salt
Ingredient		
Milo, ground	66.65	62.78
Wheat middlings	21.00	21.00
Molasses, sugarcane	4.80	4.80
Limestone	4.00	4.00
Dicalcium Phosphate	2.55	2.55
Fine Mixing Salt	0.50	4.00
Magnesium Oxide	0.35	0.75
Rumensin 60 Premix	0.15	0.12
mg monensin/kg suppl.	198	165

Table 2. Effect of supplementation on rumen response of steers. Year 1.

Item	Control	Monensin Low Salt	Monensin High Salt	SEM	Contrast, *P*-value< Supplement	Salt
Number of steers	3	3	3	-	-	-
pH	5.83	5.62	5.78	0.17	.55	.53
NH_3-N(mg/100ml)	20.27	18.59	16.53	3.80	.58	.72
Osmolarity (mOsm/kg)	313.94	345.72	342.61	15.61	.17	.89
Acetate[a]	56.38	51.42	52.71	1.11	.02	.44
Propionate[a]	21.12	25.20	28.79	2.39	.09	.33
Butyrate[a]	16.77	15.89	12.73	2.80	.50	.46
Isobutyrate[a]	.99	1.06	.70	.16	.61	.17
Valerate[a]	2.71	4.62	3.60	1.79	.55	.70
Isovalerate[a]	2.02	1.80	1.46	.37	.43	.55
Acetate:Propionate	2.68	2.13	1.86	0.21	.04	.40
Rumen Na (g/L)	1.75	2.18	2.45	0.13	.01	.20
Rumen K (g/L)	2.10	1.67	1.36	0.15	.02	.19
Na:K	0.88	1.33	1.87	0.16	.01	.06

[a]Mol/100 mol

Table 3. Effect of supplementation on rumen response of steers. Year 2.

Item	Control	Monensin Low Salt	Monensin High Salt	SEM	Contrast, *P*-value< Supplement	Salt
Number of steers	3	3	3	-	-	-
pH	6.72	6.45	6.55	.12	.20	.63
NH_3-N(mg/100 ml)	8.96	6.58	3.94	.734	.01	.04
Total VFA[a]	94.18	107.78	97.17	7.03	.37	.33
Acetate[b]	67.12	65.25	65.82	.48	.04	.44
Propionate[b]	16.76	18.45	20.15	.56	.01	.07
Isobutyrate[b]	1.48	1.29	1.23	.07	.03	.52
Valerate[b]	1.32	1.09	.94	.05	.01	.06
Isovalerate[b]	1.77	1.44	1.49	.11	.07	.76
Acetate:Propionate	4.02	3.56	3.28	.13	.01	.18
Na:K	3.41	2.49	3.61	.16	.12	.01

[a]mMol/L
[b]Mol/100mol

Table 4. Chemical composition of forage(%DM basis).

	Year 1	SD	Year 2	SD
Number of samples	4		4	
Dry matter	-	-	29.35	.85
Crude protein	20.43	.70	19.08	.87
Sodium	.04	.005	.03	.005
Potassium	1.78	.10	1.96	.25

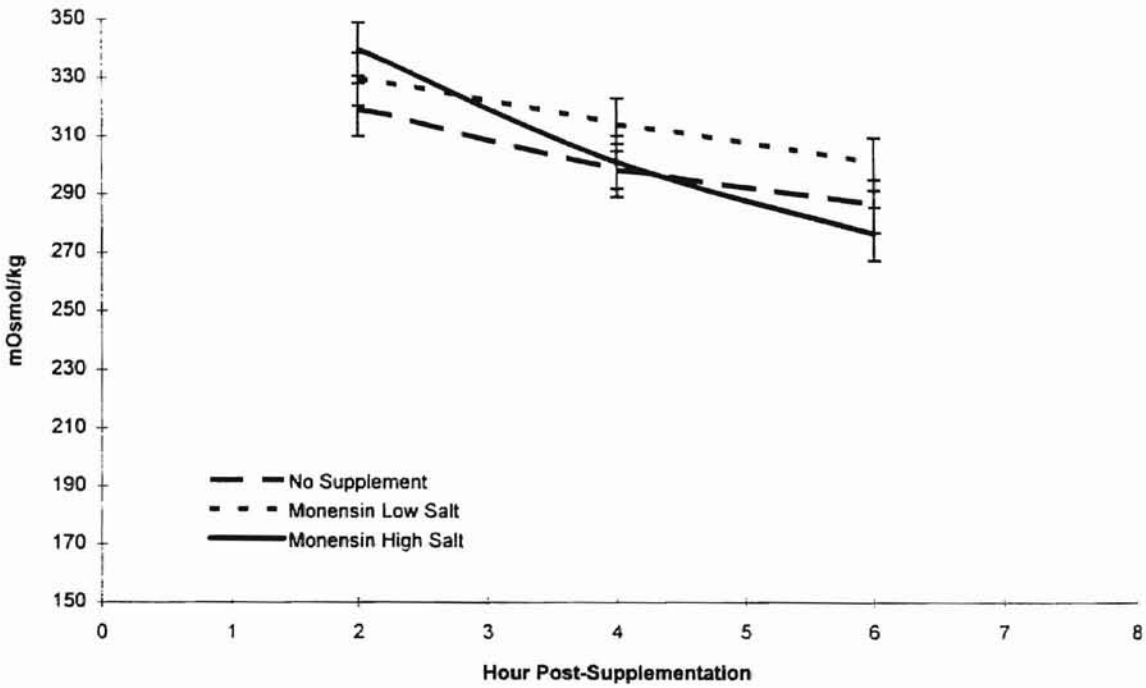

Figure 1. Effect of treatment on rumen fluid osmolality (mOsmol/kg) across sampling times in Year 2. Error bars represent SEM (27 observations).

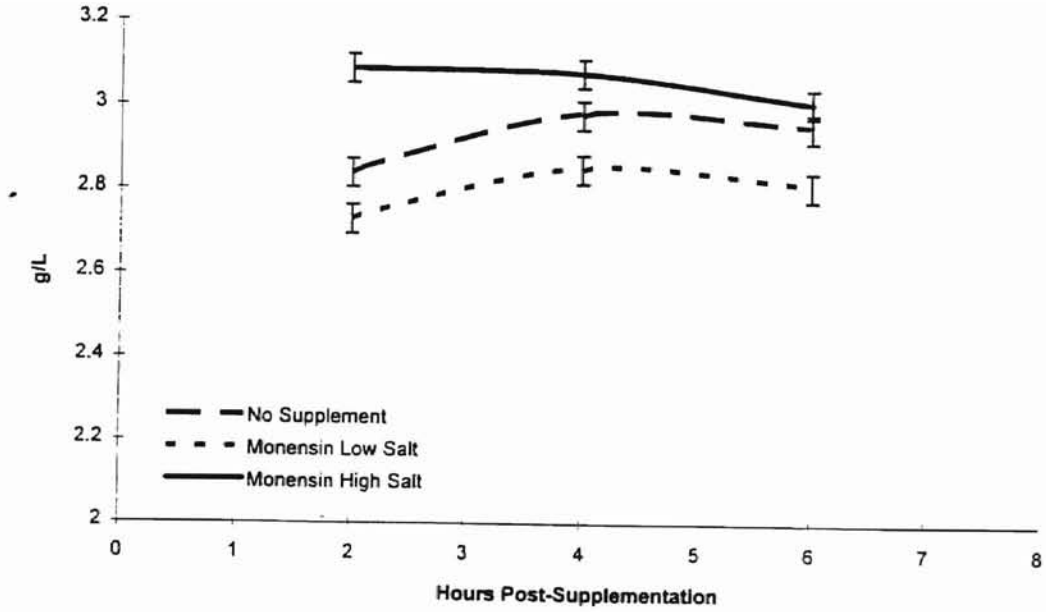

Figure 2. Effect of treatment on rumen soluble sodium (g/L) across sampling times in Year 2. Error bars represent SEM (27 observations).

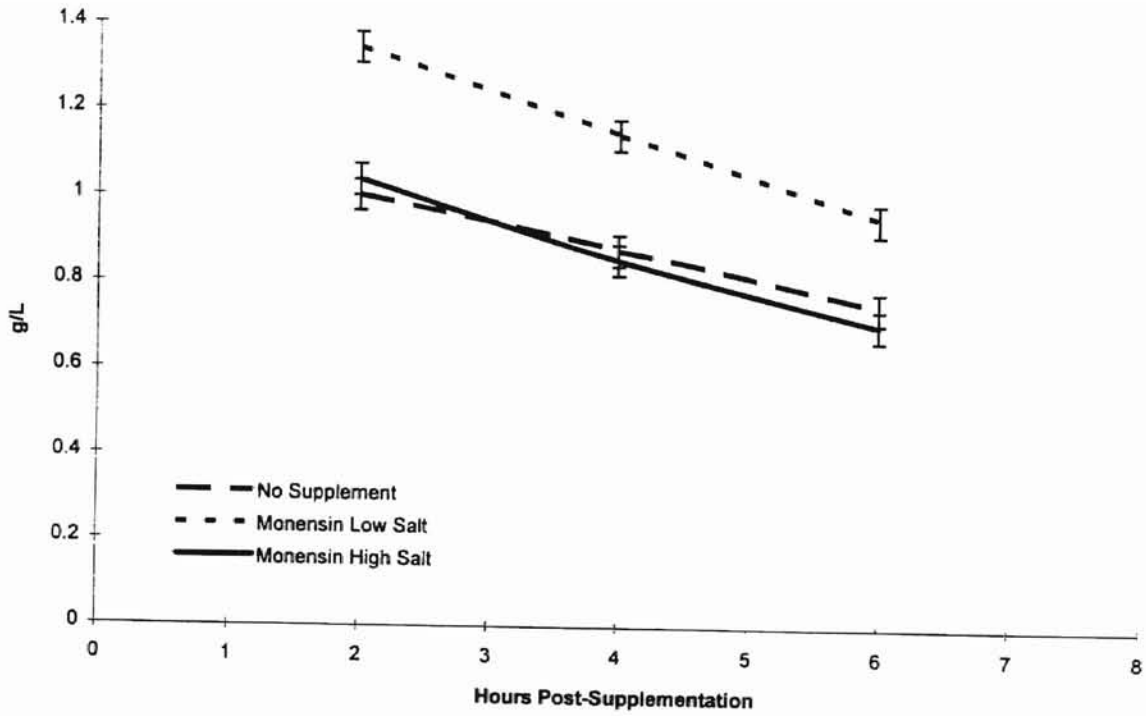

Figure 3. Effect of treatment on rumen soluble potassium (g/L) across sampling times in Year 2. Error bars represent SEM (27 observations).

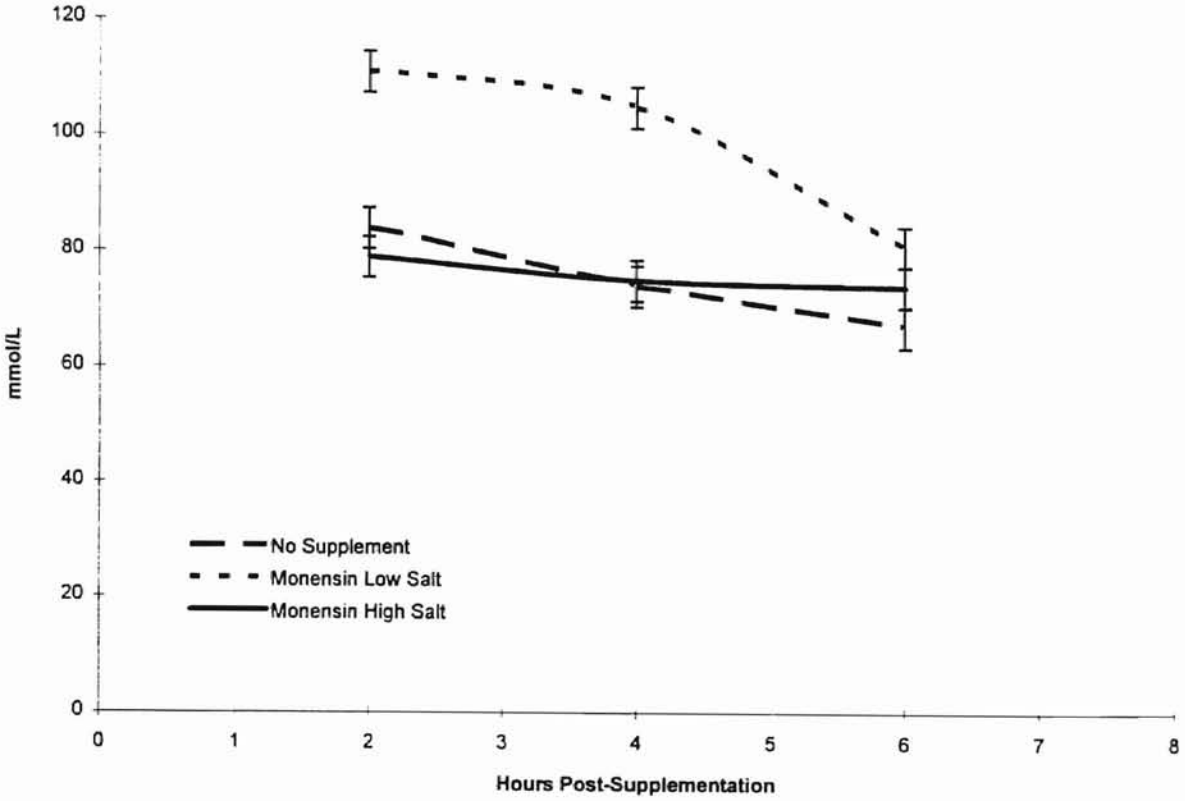

Figure 4. Effect of treatment on total rumen VFA concentrations (mmol/L) across sampling times in Year 1. Error bars represent SEM (27 observations).

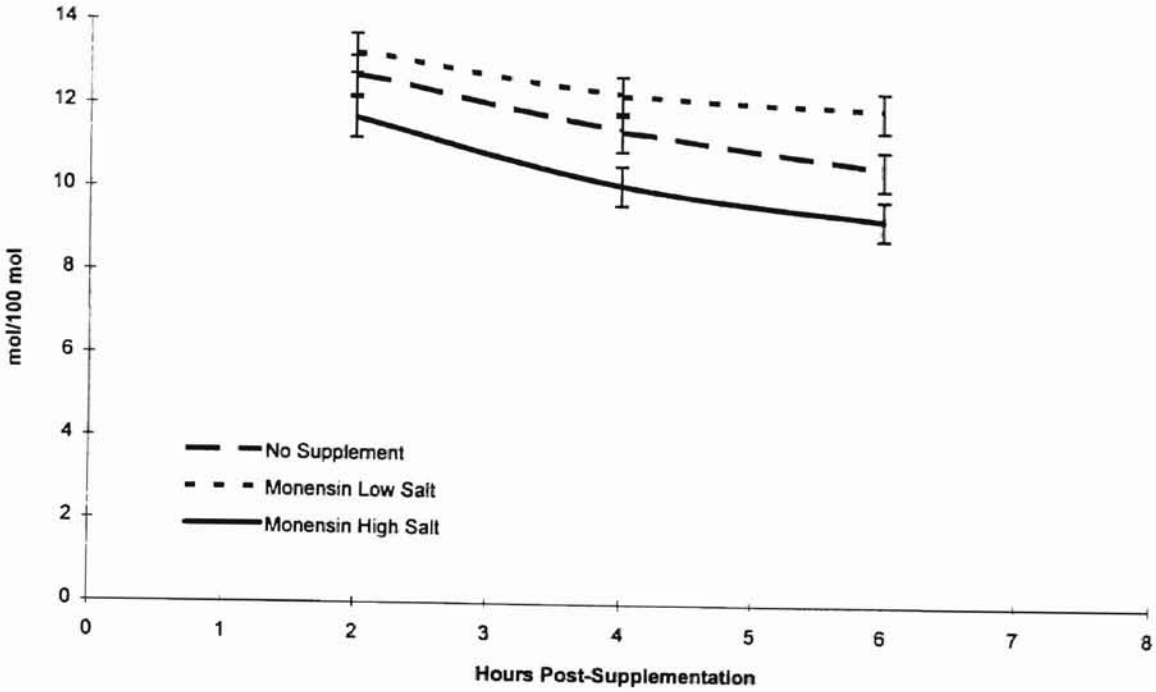

Figure 5. Effect of treatment on rumen butyrate (mol/100mol) across sampling times in Year 2. Error bars represent SEM (27 observations).

Chapter 4

EFFECTS OF ALTERNATE-DAY FEEDING OF A MONENSIN-CONTAINING ENERGY SUPPLEMENT TO STOCKER CATTLE GRAZING WHEAT PASTURE

J.G. Andrae and G.W. Horn

ABSTRACT

Forty-two fall-weaned Hereford X Angus steers (247 kg) were used in an 83-day wheat pasture grazing trial to measure weight gains of steers consuming a 1.82 kg monensin-containing energy supplement. The supplement was hand-fed every two days to 25 steers while the other 17 steers received no supplement. Mean daily intake variations were used to separate the cattle into low, moderate, and highly variable supplement consumption groups. Supplemented cattle were also divided into groups consisting of 1) steers consuming less than 140 mg monensin/day and 2) steers consuming greater than 140 mg monensin/day. Steers receiving the monensin supplement gained .25 $kg \cdot hd^{-1} \cdot d^{-1}$ more ($P < .01$) than the unsupplemented steers. Cattle with a low variation in supplement intake had greater daily gains ($P < .05$) than steers with highly variable supplement intake. All intake variation groups differed ($P < .05$) in mean supplement intake per head. Steers with high monensin (supplement) intakes had greater ($P = .04$) rates of gain

than steers with low monensin (supplement) intakes. Monensin-containing energy supplementation increased daily weight gains of stocker cattle, and reducing supplement intake variability improved supplement intake and daily gains of stocker cattle grazing wheat pasture.
(Key Words: Monensin, Intake Variation, Growing Cattle, Wheat Pasture)

Introduction

In previous studies aimed at developing a self-limiting monensin-containing energy supplement for growing cattle on wheat pasture, daily gains were consistently increased by about .23 $kg \cdot hd^{-1} \cdot d^{-1}$ and profits were increased by $15 to $31 per head, depending on feed cost and cattle profit potential (Beck et al., 1993; Horn et al., 1990, 1992). While some producers prefer self-fed supplements, others prefer hand feeding. Thus, one objective of this study was to determine the effects of hand-feeding a monensin-containing energy supplement on an every other day basis to stocker cattle grazing wheat pasture. Decreased gain and efficiency of feedlot cattle have also been observed when intake variability was artificially increased (Galyean et al., 1992). Therefore, the effects of supplement intake

variability and monensin intake levels on gain were also assessed.

Experimental Procedure

Forty-two fall-weaned Hereford x Angus steers with a mean initial weight of 247 ± 24 kg were randomly allotted to two treatments. One treatment was a negative control and received no supplement, while the other treatment received a monensin-containing energy supplement. Both groups were allowed to graze the same wheat pasture in the 83-day trial beginning December 31, 1992 and ending March 23, 1993. All animals were gathered from the pasture every two days. Steers in the supplemented group were placed in individual feeding stalls and hand-fed 1.82 kg of the supplement in a barn located adjacent to the wheat pasture. Two hours were allowed to consume the supplement. Following this period all animals were returned to pasture and supplement intake was measured by reweighing the unconsumed feed and subtracting from the total offered to the animal. The supplement was fed as a .48 cm (3/16 inch) pellet and contained 198 mg/kg of monensin. The supplement consisted primarily of ground milo and wheat middlings and other ingredients as shown in Table 1. Cattle weights were taken after 14 to 16 hour shrinks without feed and water. Ending weights were taken three days after final feeding of the

supplement to avoid potential fill differences from monensin supplementation (Lemenager et al., 1978).

Intake variability for each animal was calculated as the standard deviation of intake throughout the feeding period within the MEANS procedure of SAS (1985). Supplemented animals were divided into subgroups by visual examination of the data for determination of intake variation effects (Figure 1). Subgroup divisions were as follows: 1) lowly variable (supplement intake standard deviation < .41 kg/feeding); 2) moderately variable (supplement intake standard deviation .41 to .57 kg/feeding); and 3) highly variable (supplement intake standard deviation >.57 kg/feeding).

To determine average monensin (supplement) intake level effects on animal performance during the trial, supplemented animals were also divided into subgroups with mean daily monensin intakes of 1) greater than 140 mg (.76 kg supplement) per steer and 2) less than 140 mg/steer. Division at 140 mg of daily monensin intake was an arbitrary choice determined by visual assessment of the data (Figure 2).

Supplement effects on live weight gain of the steers (both intake variation and intake level) was analyzed using least squares with a one-way ANOVA in SAS (1985). Intake variation group least squares means were compared using

least significant differences after an F-test in the GLM procedure of SAS (1985) indicated significant differences between subgroups. Effects of monensin intake level were analyzed in a similar manner, but independently using least squares ANOVA.

Results and Discussion

Steers supplemented with the monensin-containing energy supplement gained .25 $kg \cdot hd^{-1} \cdot d^{-1}$ more ($P < .01$) than unsupplemented steers (Table 2). Daily supplement intake was .70 kg/head. Steers converted the supplement at 4.16 ± 2.92 kg of supplement per kg of additional weight gain. This gain response to hand-feeding the supplement on alternate days is very similar to that reported by Beck et al. (1993) and Horn et al. (1990, 1992) in which a monensin supplement of comparable feedstuff composition was self-fed to stocker cattle on wheat pasture. In these trials, supplemented cattle gained from .20 to .24 kg/day more than unsupplemented cattle and consumed 4.5 to 6.75 kg of supplement per kg of additional weight gain. These weight gains for hand-fed and self-fed monensin-containing energy supplements agree with the results of Muller et al. (1986) in which no gain differences were observed ($P > .7$) for monensin-containing energy supplements hand-fed daily or on an alternate day basis. Muller et al. (1986) also observed

no differences in cattle consuming self-fed supplements versus cattle consuming hand-fed supplements when supplement intake was equal between the feeding groups. Cattle typically grazed cool season grass pastures and consumed approximately 200 $mg \cdot hd^{-1} \cdot d^{-1}$ of monensin.

Wheat forage commonly has digestible organic matter (DOM) and crude protein (CP) levels which approach 75% and 30% of dry matter, respectively (Horn, 1984). These nutrient levels can result in DOM:CP ratios which are less than 4:1. Ratios below this level have resulted in losses of large amounts of nitrogen from the rumen due to inefficient microbial protein synthesis (Hogan, 1982). Therefore, energy supplementation to cattle grazing wheat pasture could increase this ratio and increase cattle performance.

Greater intake variation may result in an increased incidence of ruminal acidosis in feedlot cattle with monensin inclusion decreasing ration intake variation (Stock et al., 1995). Decreased animal gain and efficiency has also been observed when feed intake variation of cattle was artificially increased (Galyean et al., 1992). While ruminal acidosis may not be a major concern with cattle grazing wheat pasture, decreasing supplement intake variability may aid in achieving uniform target intakes and help to optimize performance. Supplement intake and intake

variation were inversely related in that as variation decreased intake levels increased (Table 3). Mean supplement intake also differed ($P < .05$) among all three intake variation groups suggesting that steers with the least variable intakes consumed the entire amount of offered supplement more often than steers in high variation intake groups. Daily weight gains increased as variation in supplement intake decreased. Weight gains of the low variation group were .23 kg/day greater ($P < .05$) than the high variation group, and the moderate variation group gained at an intermediate rate. However, cattle with low intake variation consumed more supplement ($P < .05$). It is unclear if decreased weight gains were the result of low supplement intake levels or high supplement intake variation, but cattle with increasing variation in supplement intake also had numerically increased supplement conversion ratios. This suggests that intake variation may have been the greater factor in decreasing daily weight gains.

Supplemented steers with monensin intakes greater than 140 mg/day had greater ($P = .04$) weight gains than steers with monensin intakes of less than 140 mg/day (Table 4). Because monensin intake levels are a function of supplement intake, and high intake levels are related to groups of cattle with low intake variation, specific reasons for

decreased performance (i.e. monensin, energy level or intake variation) are not distinguishable. Previous work with ionophore-containing energy supplementation on good to high quality pastures (Andersen and Horn, 1987; Potter et al., 1976, 1986) suggested that ionophore and energy gain responses were additive as energy supplementation increased gain ($P < .05$) approximately .09 $kg \cdot hd^{-1} \cdot d^{-1}$ and monensin increased gain an additional .09 $kg \cdot hd^{-1} \cdot d^{-1}$ ($P < .05$). Monensin doses of greater than 100 $mg \cdot hd^{-1} \cdot d^{-1}$ have increased ($P < .05$) daily weight gains of cattle grazing average to high quality pasture (Potter et al., 1976; Horn et al., 1988). Thus, lower rates of gain in cattle consuming less than 140 $mg \cdot hd^{-1} \cdot d^{-1}$ of monensin could be the result of decreased supplemental energy consumption or a combination of lower supplemental intake levels of energy and monensin.

Implications

Alternate day hand-feeding of a monensin-containing energy supplement to growing cattle on wheat pasture resulted in a .25 $kg \cdot hd^{-1}d^{-1}$ increase in daily gains. Steers with greater supplement intake variation had decreased daily gains and supplement intake levels. Steers with monensin intakes of less than 140 mg/day had lower daily gains than steers consuming greater than 140 mg/day of monensin. These

data accentuate the importance of not only formulating supplements and managing supplementation programs to achieve desired mean intakes by the herd, but also to minimize the variability of supplement intake.

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Table 1. Feedstuff composition of monensin-containing energy supplement.

Ingredient	% As-fed
Ground milo	66.65
Wheat middlings	21.00
Sugarcane molasses	4.80
Limestone	4.00
Dicalcium phosphate	2.55
Salt[a]	.50
Magnesium oxide	.35
Rumensin 60 Premix	.15
Monensin content, mg/kg supplement	198

[a] Fine mixing salt (99.5% NaCl).

Table 2. Mean supplement intake, conversion and weight gains of steers.

	Unsupplemented	SEM	Supplemented	SEM
Number of steers	17		25	
Initial weight, kg	241	6.55	251	4.40
Final weight, kg	332[a]	6.06	362[b]	5.00
Supplement intake, kg/day	--	--	.70	.02
Daily gain, kg	1.05[a]	.02	1.30[b]	.03
kg supplement/kg added gain	--	--	4.16	.58

[a,b] Means in the same row with uncommon superscripts differ ($P < .001$).

Table 3. Effects of variation in supplement intake (% as-fed basis) on performance.

	Intake Variation per feeding < .41 kg	SEM	Intake Variation per feeding .41-.57 kg	SEM	Intake Variation per feeding > .57 kg	SEM
Number of steers	8	-	11	-	6	-
Supplement intake, kg/day	.83[a]	.007	.71[b]	.021	.53[c]	.012
Monensin intake, mg/day	163[a]	1.52	142[b]	4.45	105[c]	2.68
Daily gain, kg	1.39[a]	.042	1.29[ab]	.045	1.16[b]	.045
kg supplement/kg added gain	3.21	.972	4.09	.660	5.76	1.96

[a,b,c] Rows with uncommon superscripts differ ($P < .05$).

Table 4. Effects of monensin intake levels on performance.

	Monensin Intake <140 mg·hd^{-1}·d^{-1}	SEM	Monensin Intake >140 mg·hd^{-1}·d^{-1}	SEM
Number of steers	9		16	
Monensin intake, mg/d	110[a]	3.04	157[b]	2.03
Daily gain, kg	1.21[a]	.047	1.34[b]	.035
kg supplement/kg added gain	4.67	1.31	3.88	.637

a,b Rows with uncommon superscripts differ ($P < .05$).

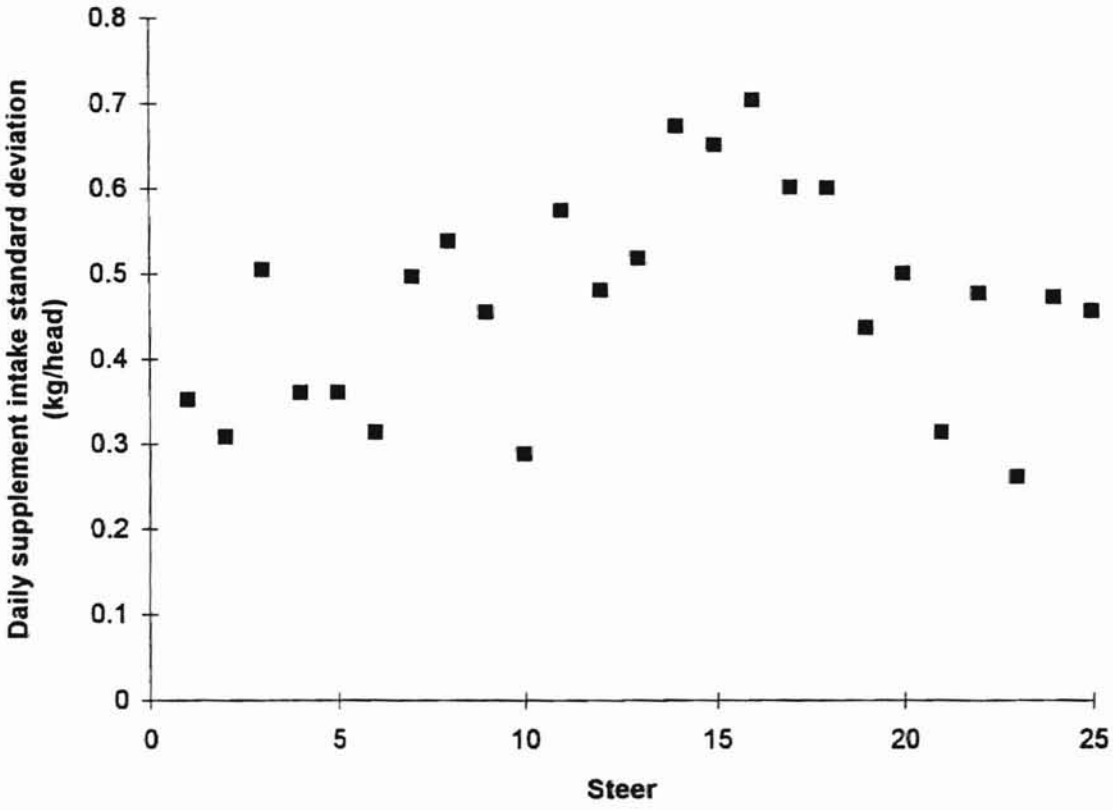


Figure 1. Supplement intake standard deviation of individual steers.

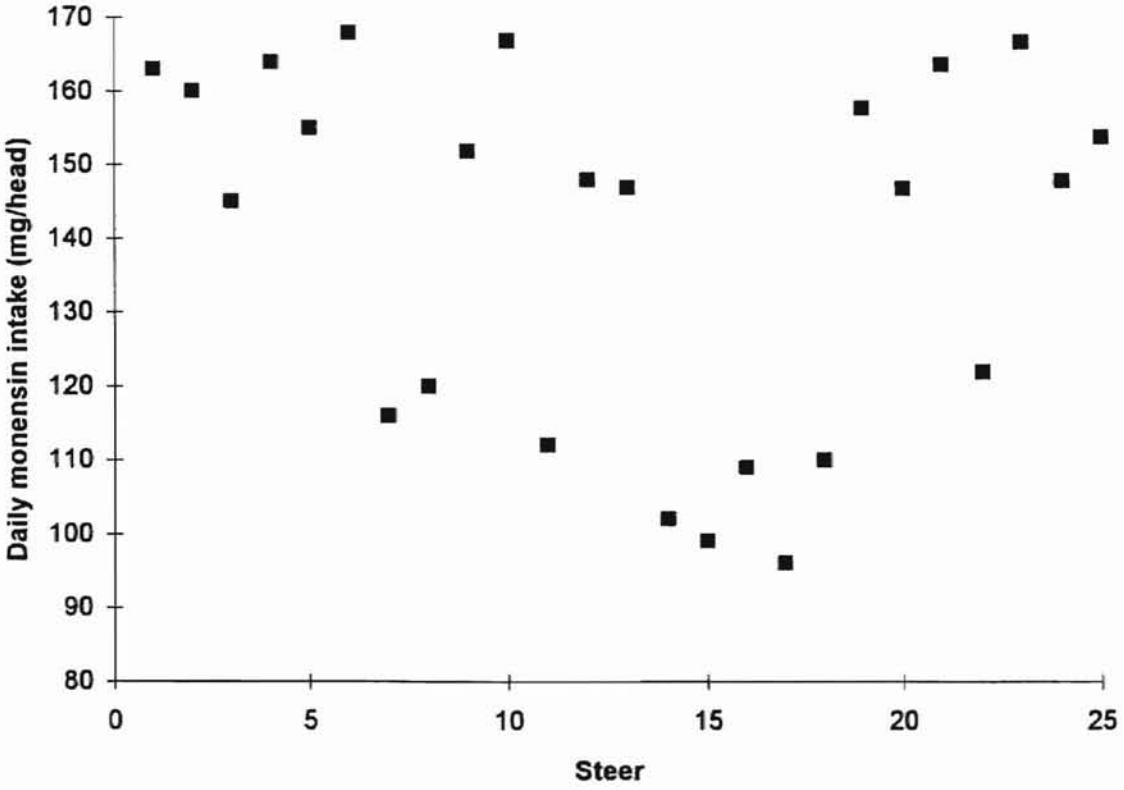


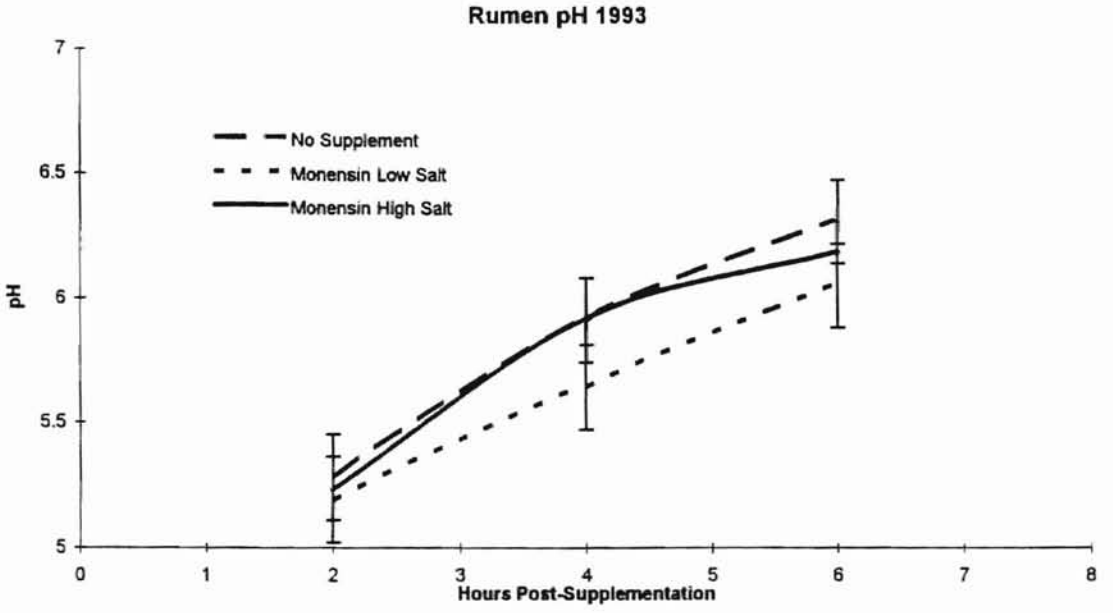
Figure 2. Daily monensin (mg/head) intake of individual steers.

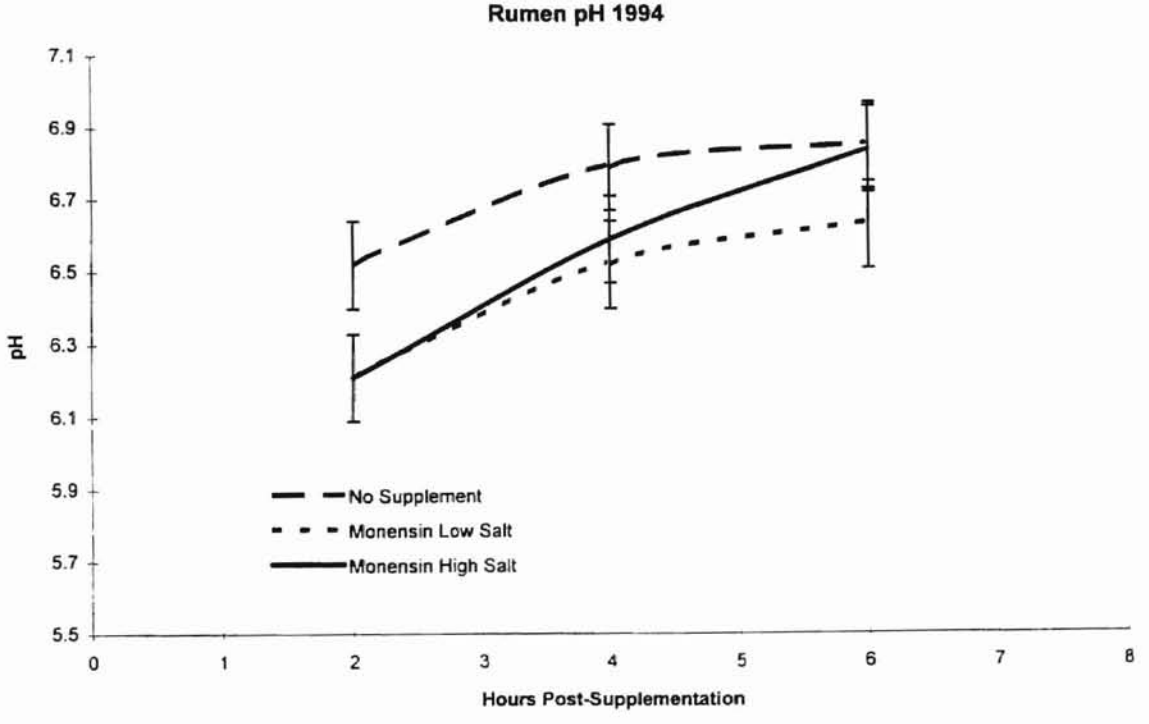
APPENDIX

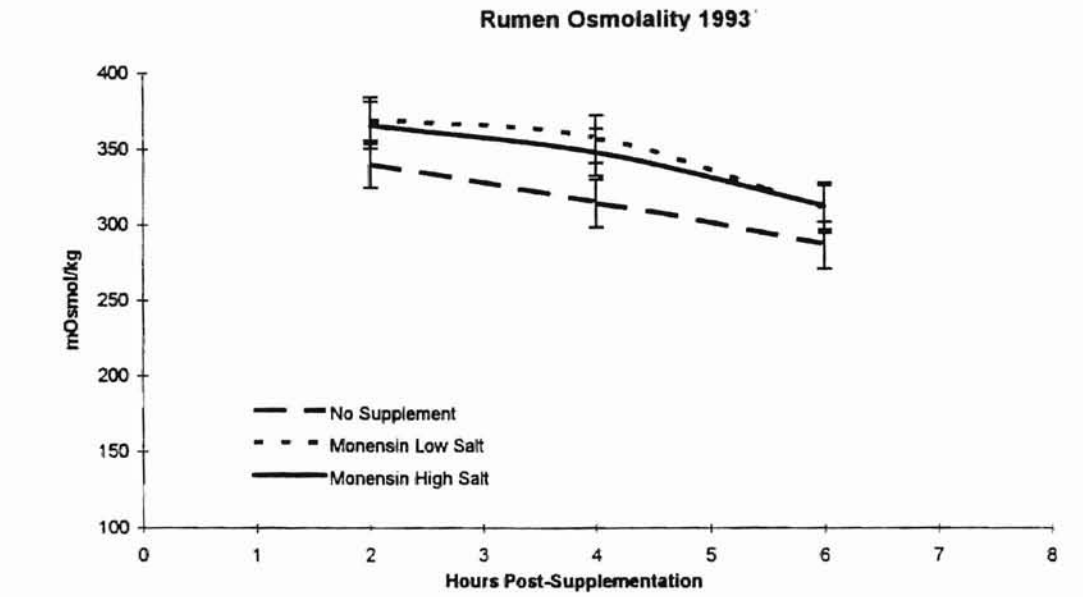
Appendix 1. *P*-values for supplement x sampling time interactions in 1993 and 1994.

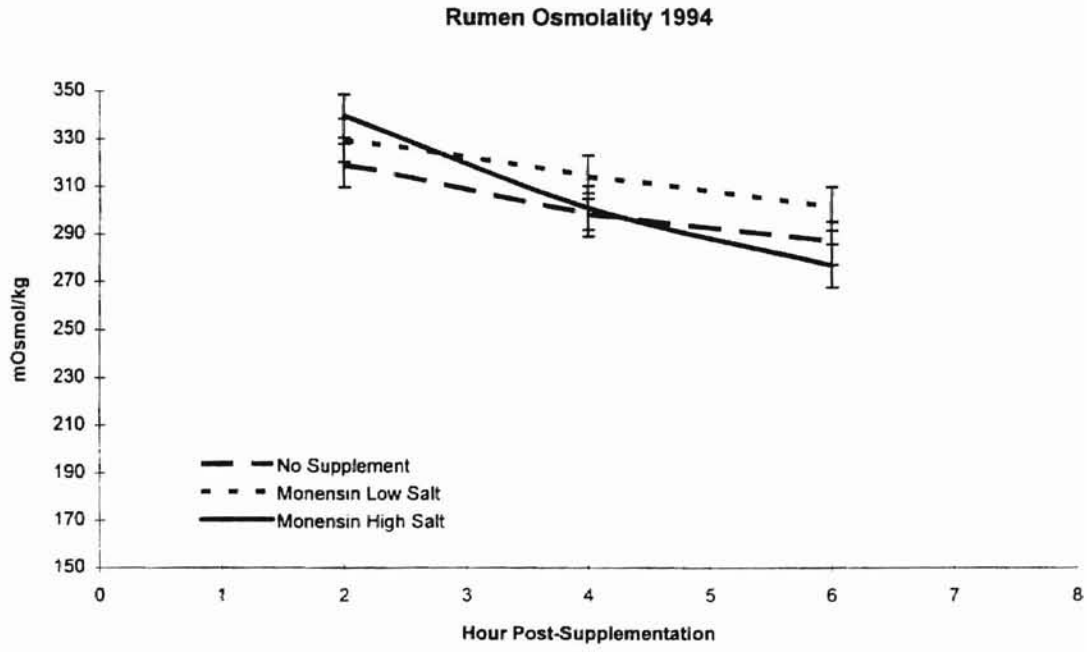
	Supplement x Sampling Time P<	
	1993	1994
Rumen pH	.89	.31
Rumen Osmolality	.93	.01
NH_3-N	.77	.62
Rumen Soluble Na	.73	.01
Rumen Soluble K	.94	.03
Rumen Na:K	.34	.36
Total VFA (mmol/L)	.06	.25
Acetate (mol/100 mol)	.73	.66
Propionate (mol/100 mol)	.62	.23
Butyrate (mol/100 mol)	.42	.12
Isobutyrate (mol/100 mol)	.47	.89
Valerate (mol/100 mol)	.57	.85
Isovalerate (mol/100 mol)	.70	.83
Acetate:Propionate	.44	.34

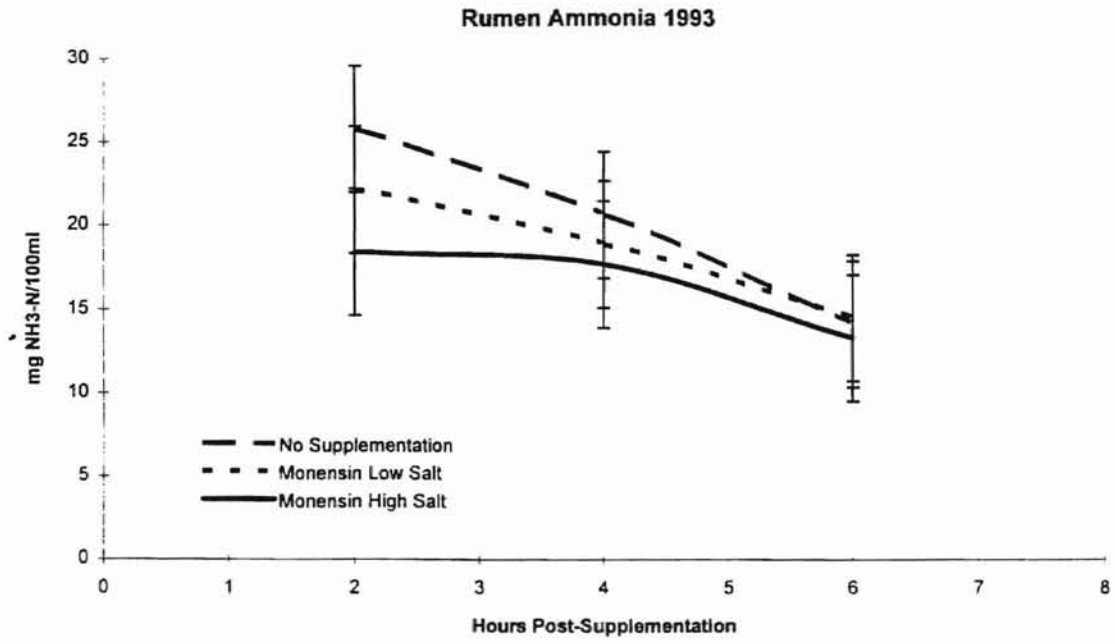
Appendix 2. Treatment means across sampling times in 1993 and 1994.

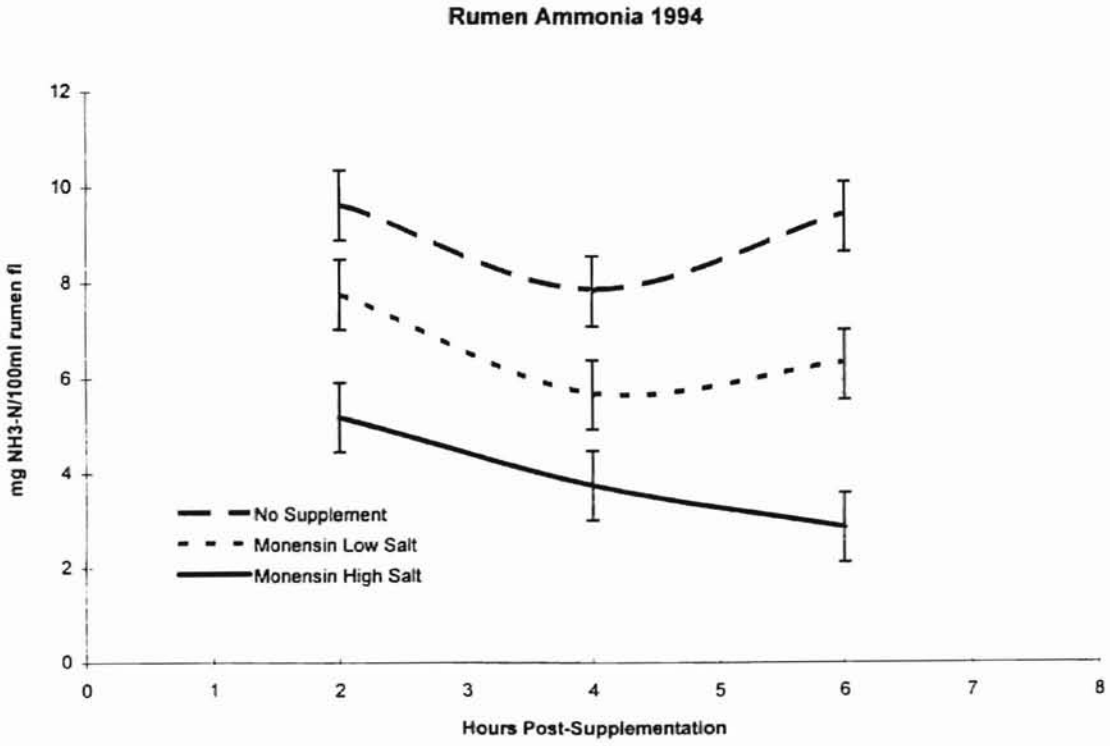


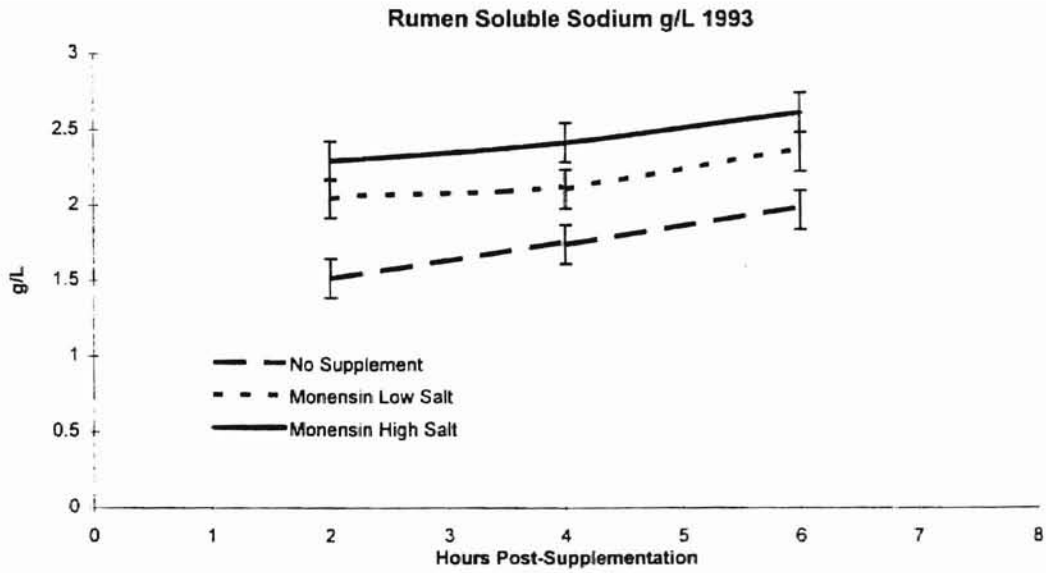


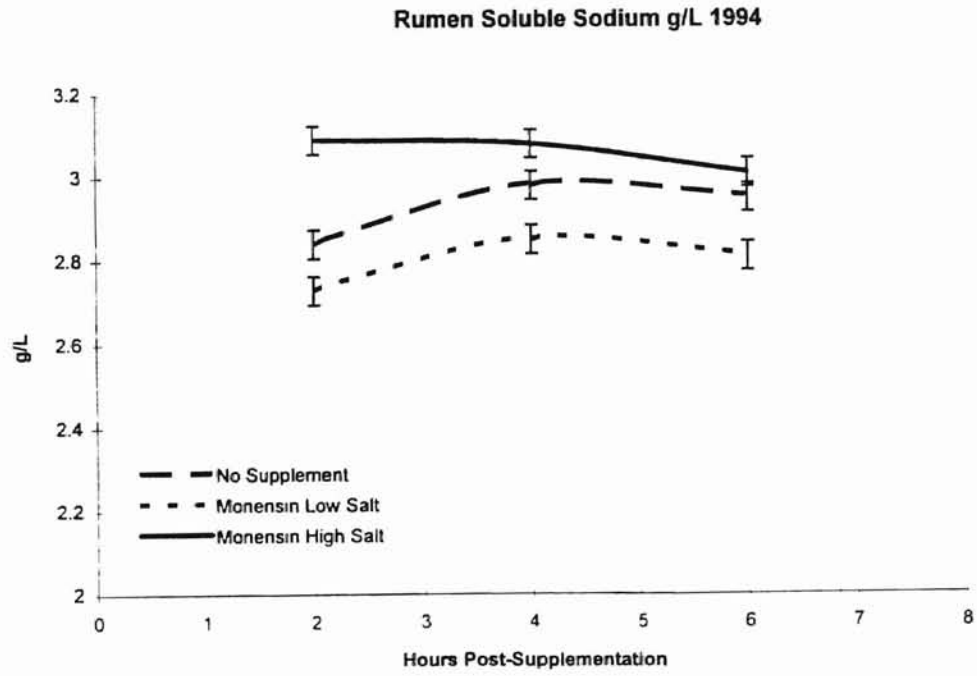

Rumen Osmolality 1993
400
350
300
250
200
150
100
mOsmol/kg
No Supplement
Monensin Low Salt
Monensin High Salt
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation

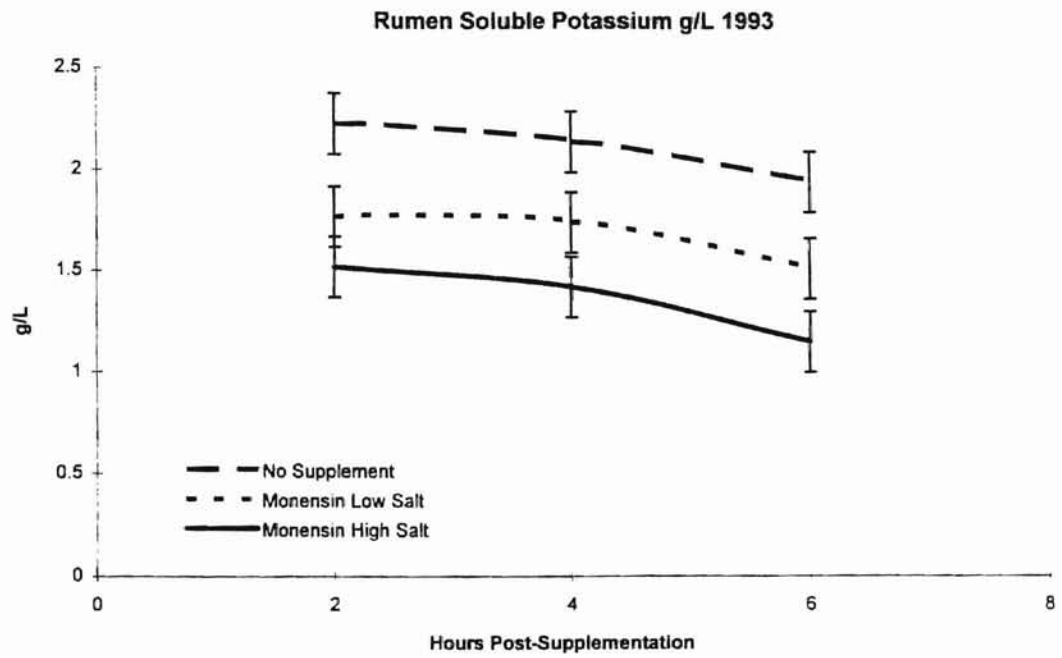

Rumen Osmolality 1994
350
330
310
290
270
250
230
210
190
170
150
mOsmol/kg
No Supplement
Monensin Low Salt
Monensin High Salt
0
1
2
3
4
5
6
7
8
Hour Post-Supplementation


Rumen Ammonia 1993
mg NH3-N/100ml
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplementation
Monensin Low Salt
Monensin High Salt


Rumen Ammonia 1994
mg NH3-N/100ml rumen fl
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt


Rumen Soluble Sodium g/L 1993
g/L
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt


Rumen Soluble Sodium g/L 1994
g/L
3.2
3
2.8
2.6
2.4
2.2
2
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt


Rumen Soluble Potassium g/L 1993
2.5
2
1.5
1
0.5
0
g/L
No Supplement
Monensin Low Salt
Monensin High Salt
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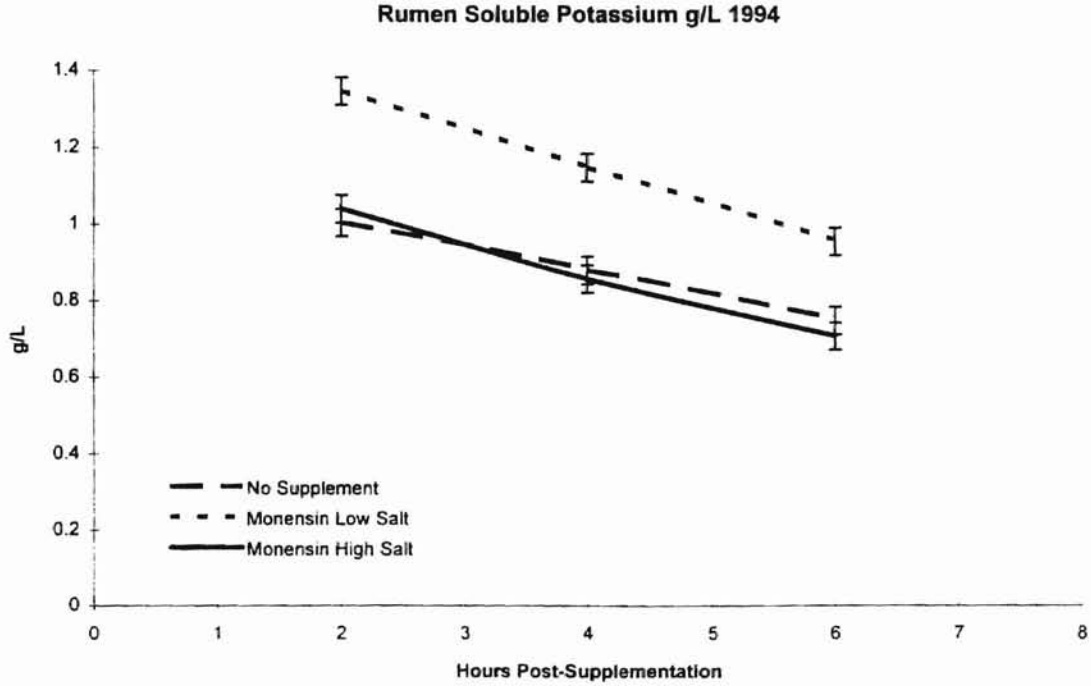
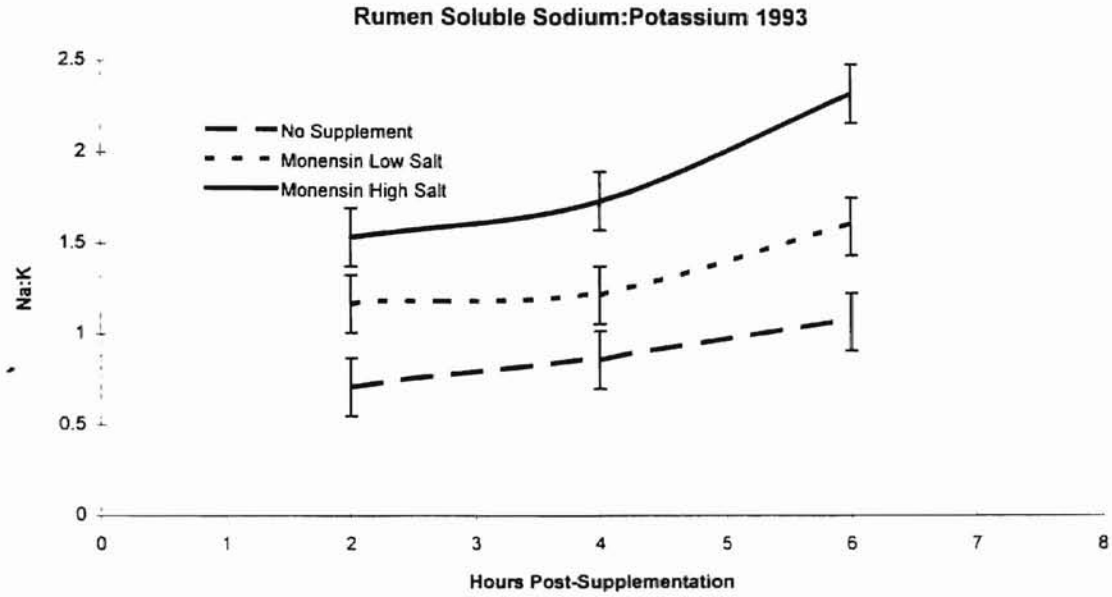
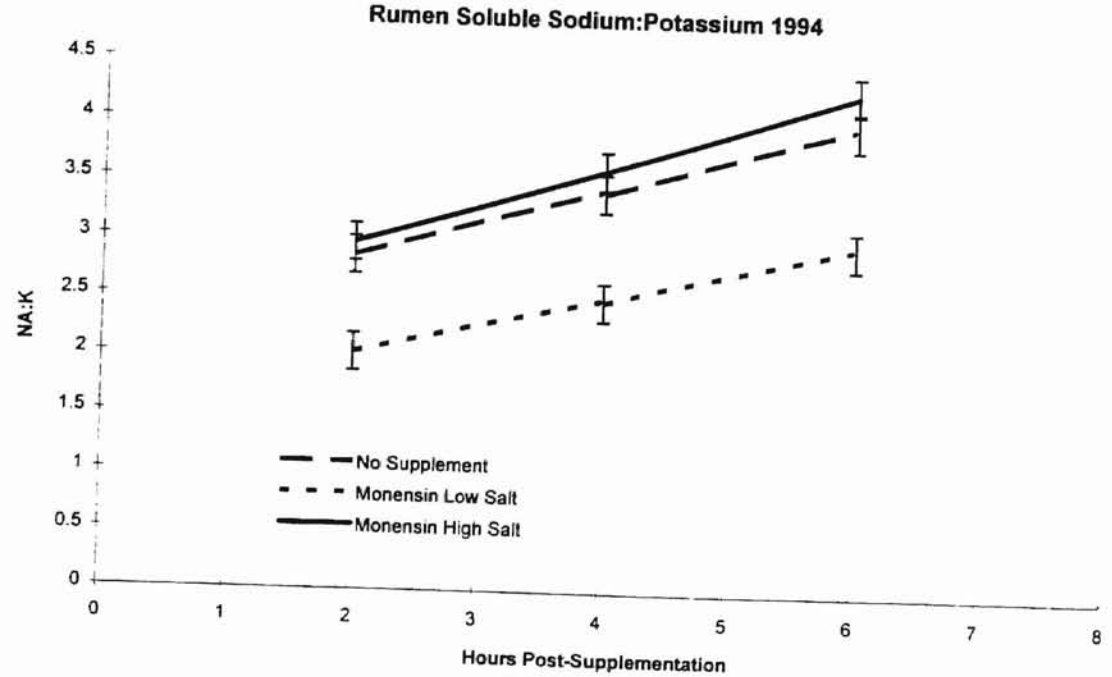
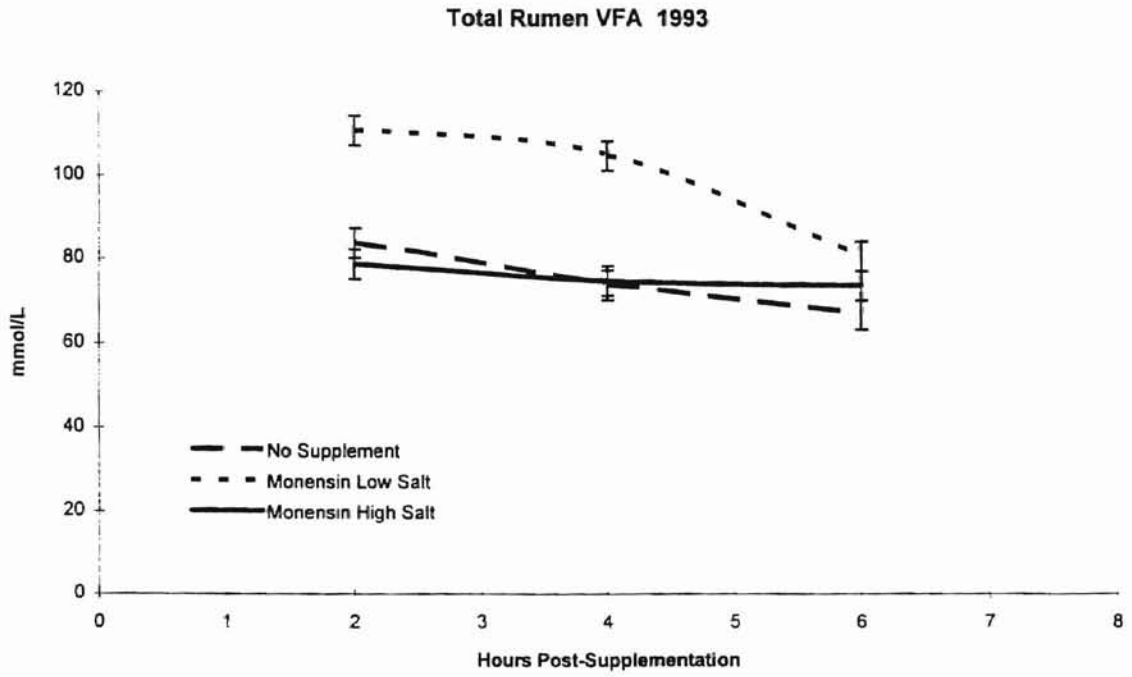
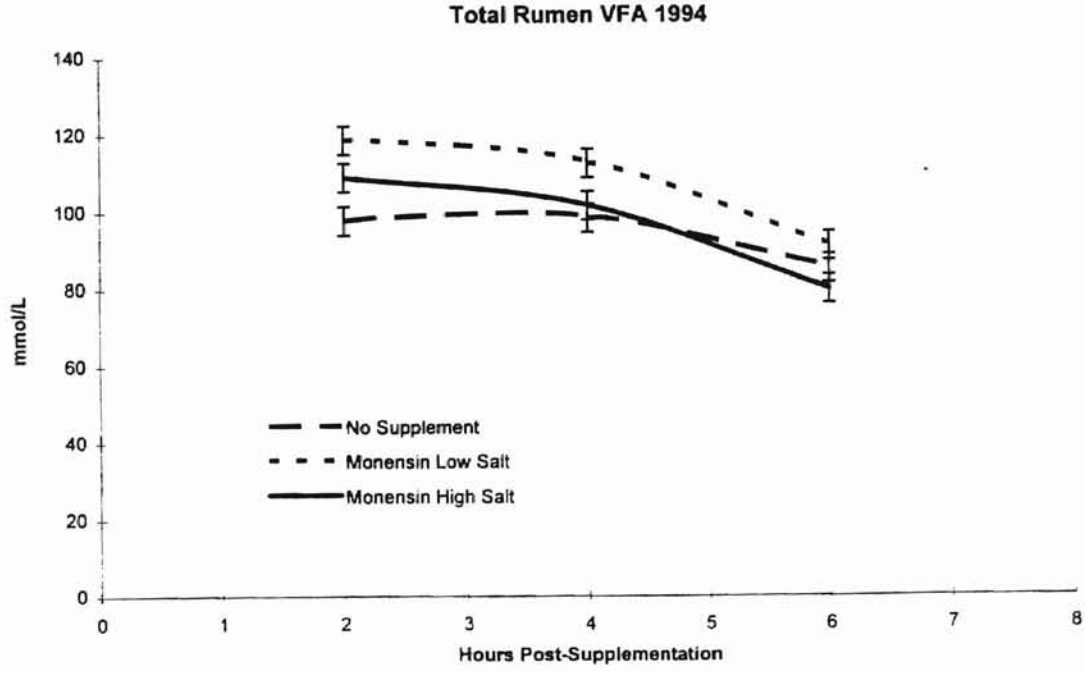
4
6
8
Hours Post-Supplementation

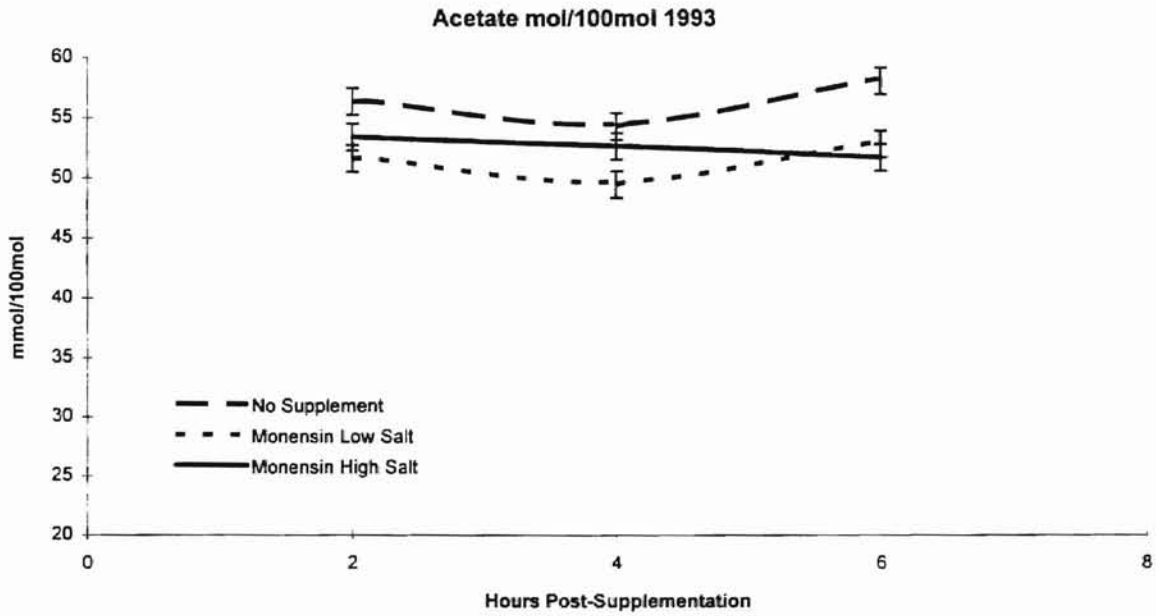

Rumen Soluble Potassium g/L 1994
1.4
1.2
1
0.8
0.6
0.4
0.2
0
g/L
No Supplement
Monensin Low Salt
Monensin High Salt
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation

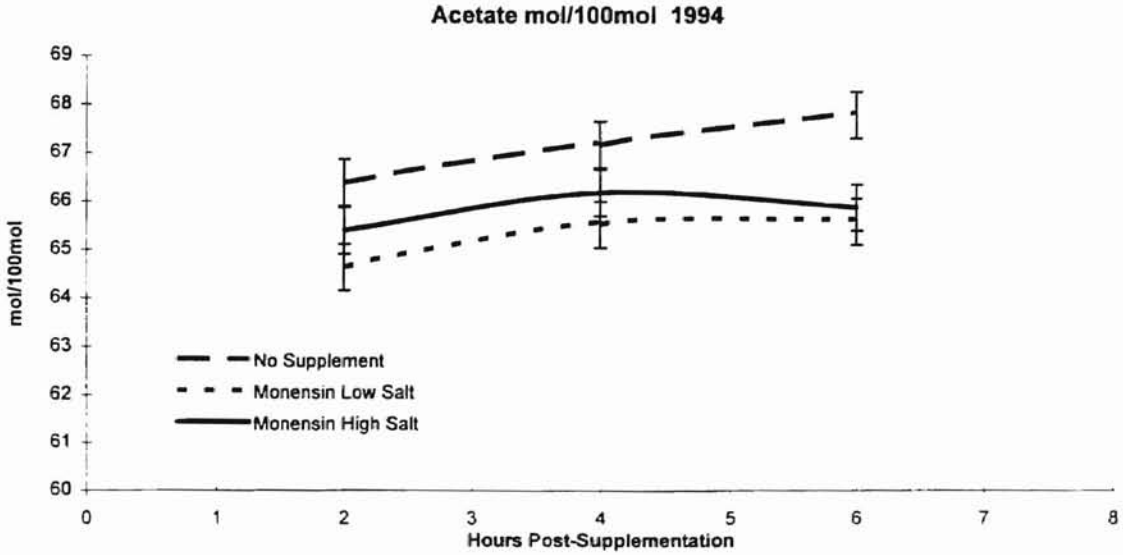

Rumen Soluble Sodium:Potassium 1993
Na:K
2.5
2
1.5
1
0.5
0
No Supplement
Monensin Low Salt
Monensin High Salt
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation

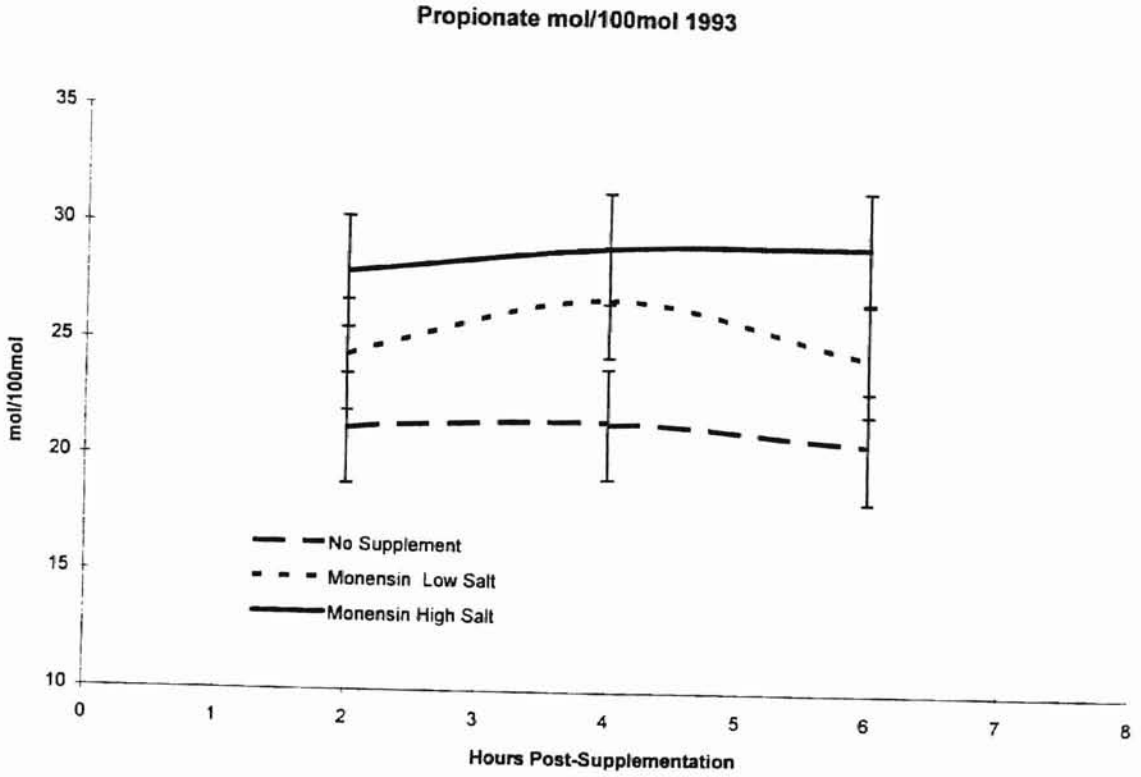

Rumen Soluble Sodium:Potassium 1994
NA:K
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
No Supplement
Monensin Low Salt
Monensin High Salt
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation

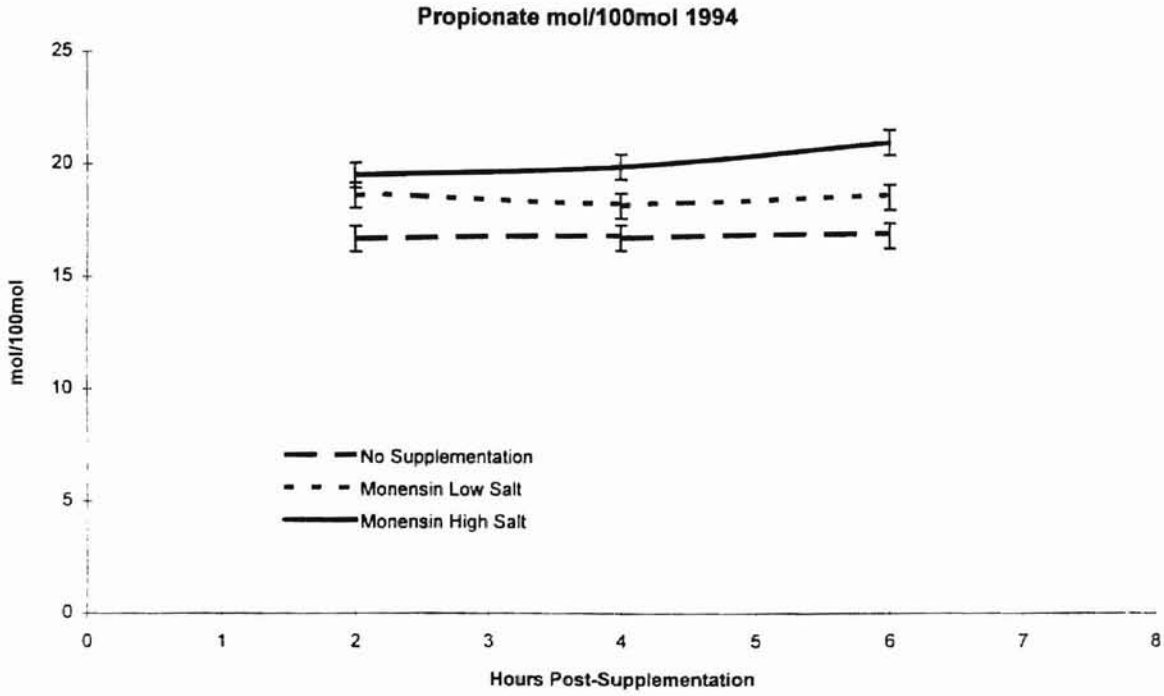

Total Rumen VFA 1993
120
100
80
60
40
20
0
mmol/L
No Supplement
Monensin Low Salt
Monensin High Salt
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation

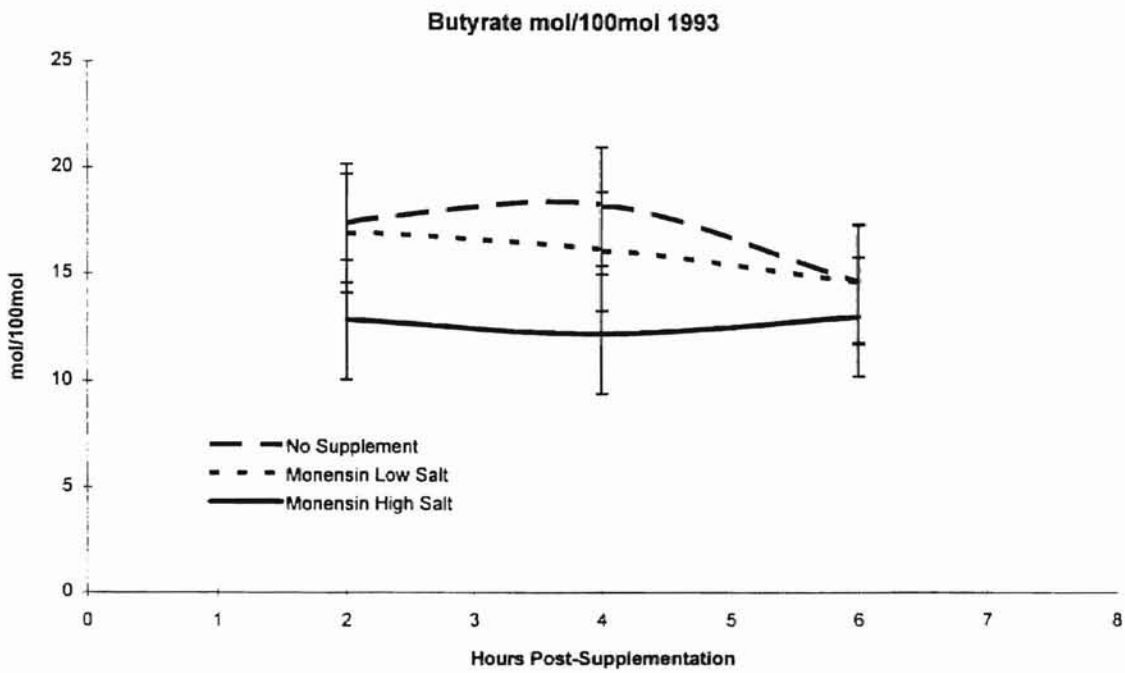

Total Rumen VFA 1994
140
120
100
80
60
40
20
0
mmol/L
No Supplement
Monensin Low Salt
Monensin High Salt
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation

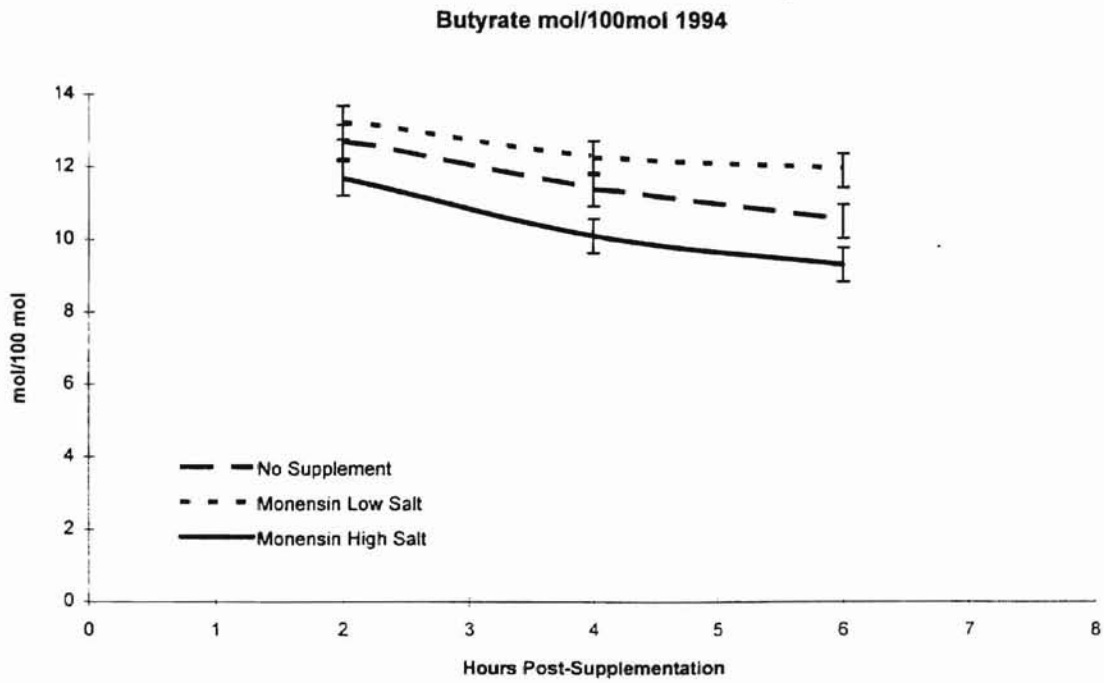

Acetate mol/100mol 1993
mmol/100mol
60
55
50
45
40
35
30
25
20
0
2
4
6
8
No Supplement
Monensin Low Salt
Monensin High Salt
Hours Post-Supplementation

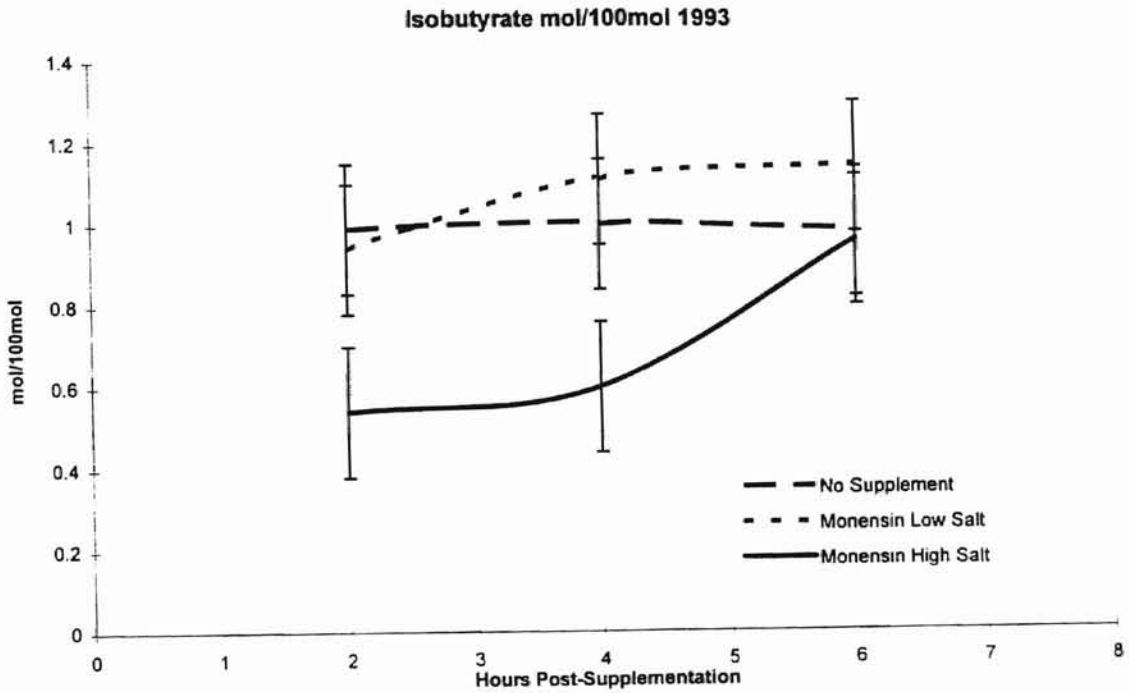

Acetate mol/100mol 1994
mol/100mol
69
68
67
66
65
64
63
62
61
60
0
1
2
3
4
5
6
7
8
No Supplement
Monensin Low Salt
Monensin High Salt
Hours Post-Supplementation

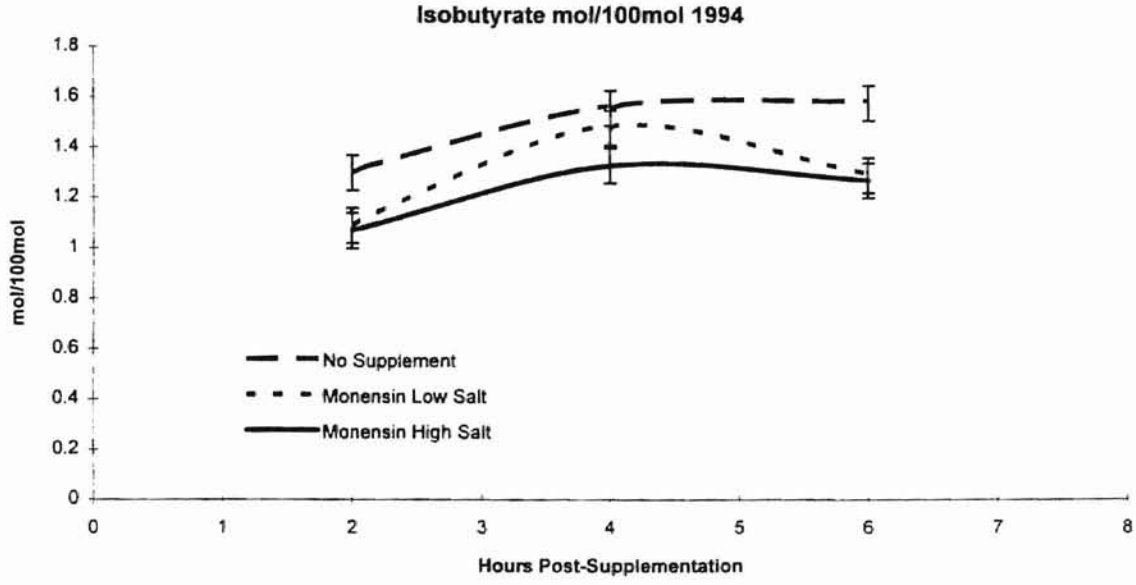

Propionate mol/100mol 1993
mol/100mol
35
30
25
20
15
10
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt

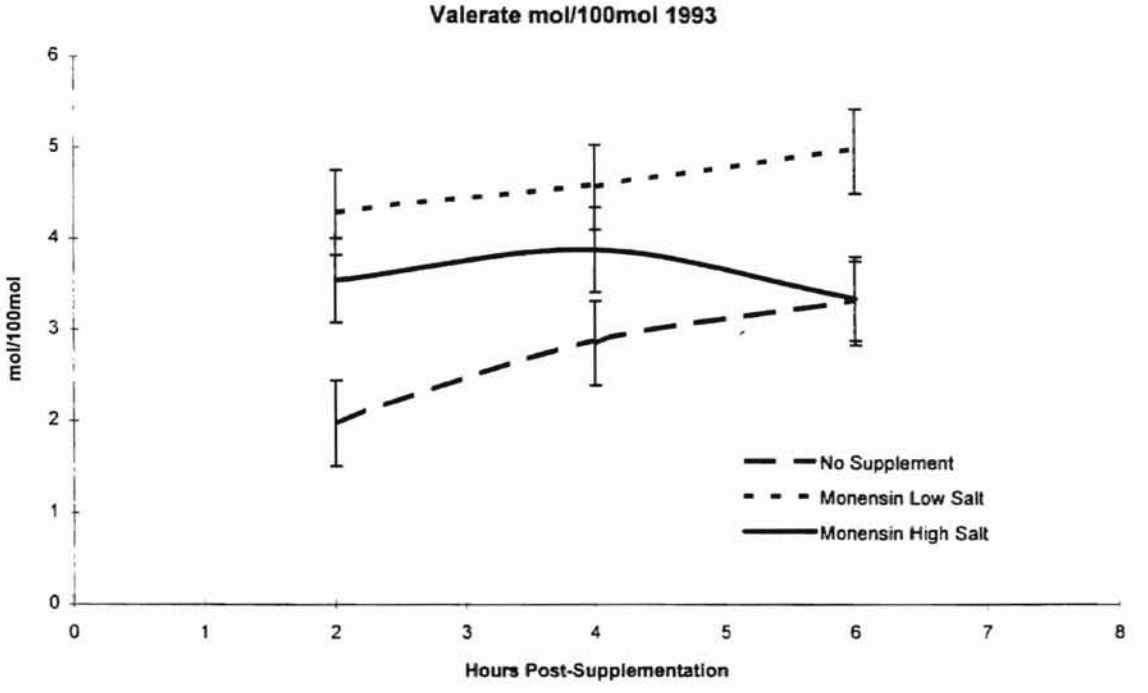

Propionate mol/100mol 1994
mol/100mol
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplementation
Monensin Low Salt
Monensin High Salt

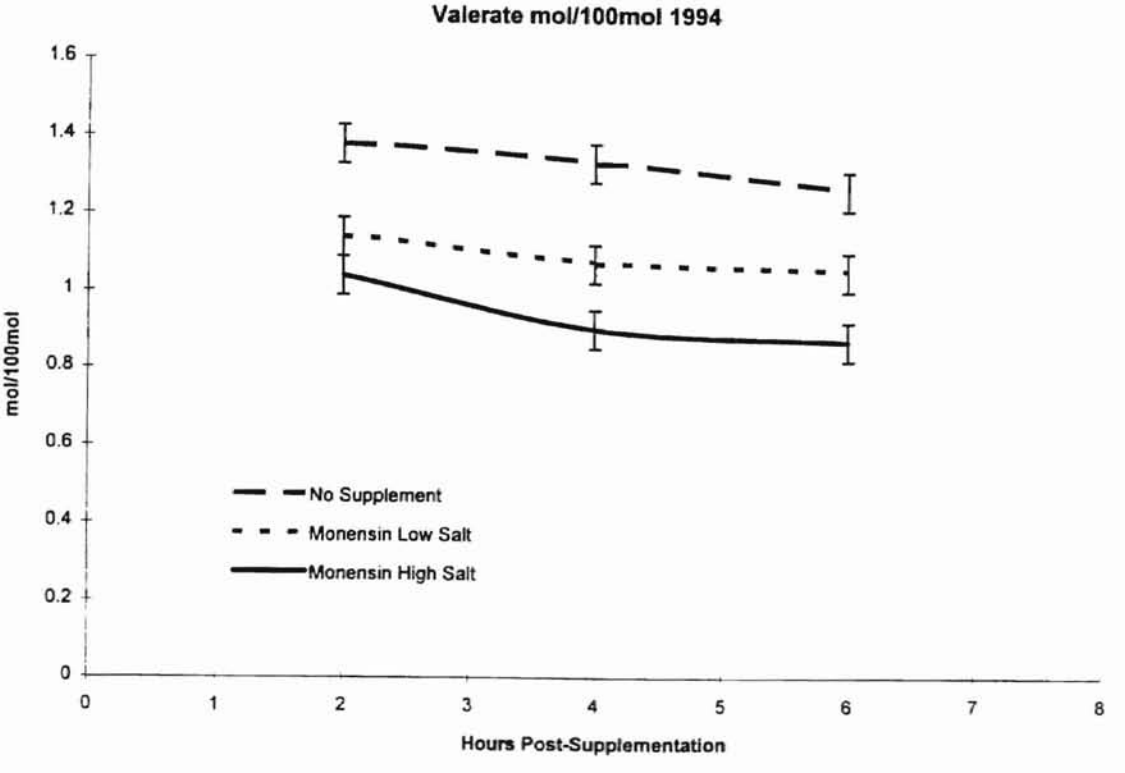

Butyrate mol/100mol 1993
mol/100mol
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
No Supplement
Monensin Low Salt
Monensin High Salt
Hours Post-Supplementation

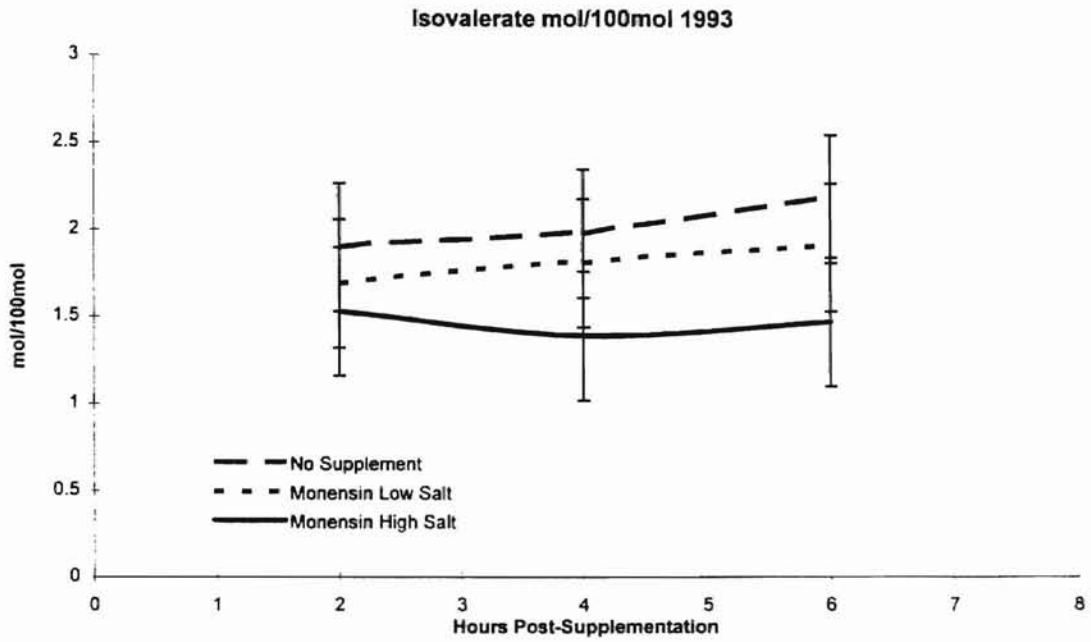

Butyrate mol/100mol 1994
mol/100 mol
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
No Supplement
Monensin Low Salt
Monensin High Salt
Hours Post-Supplementation

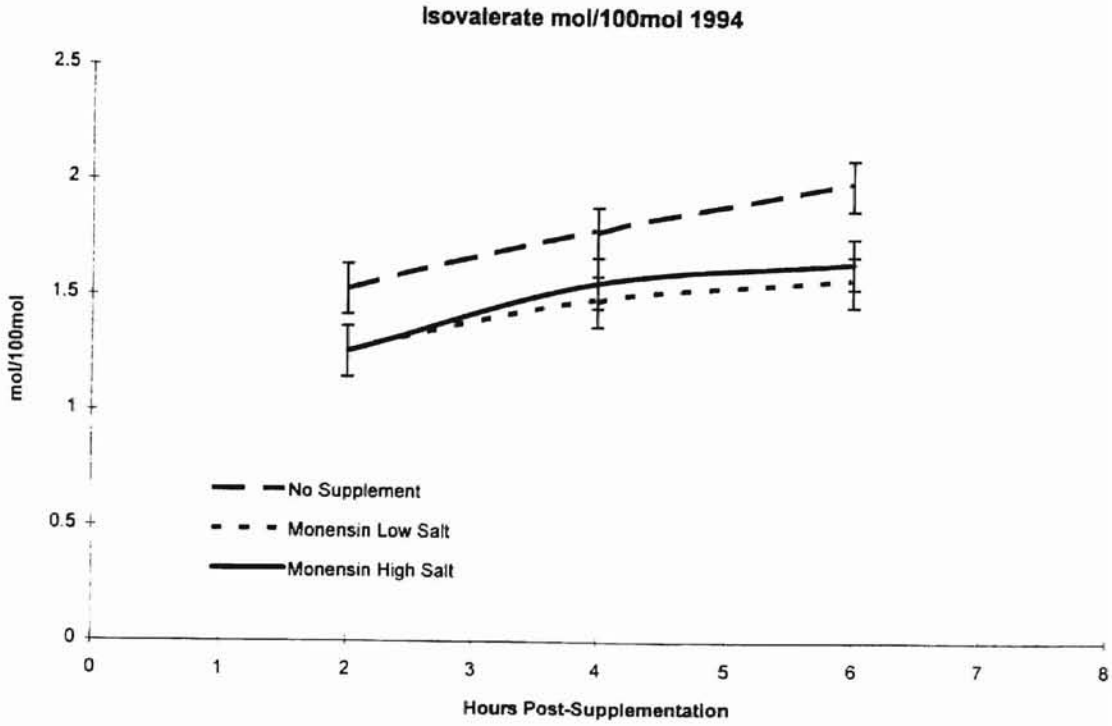

Isobutyrate mol/100mol 1993
mol/100mol
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt

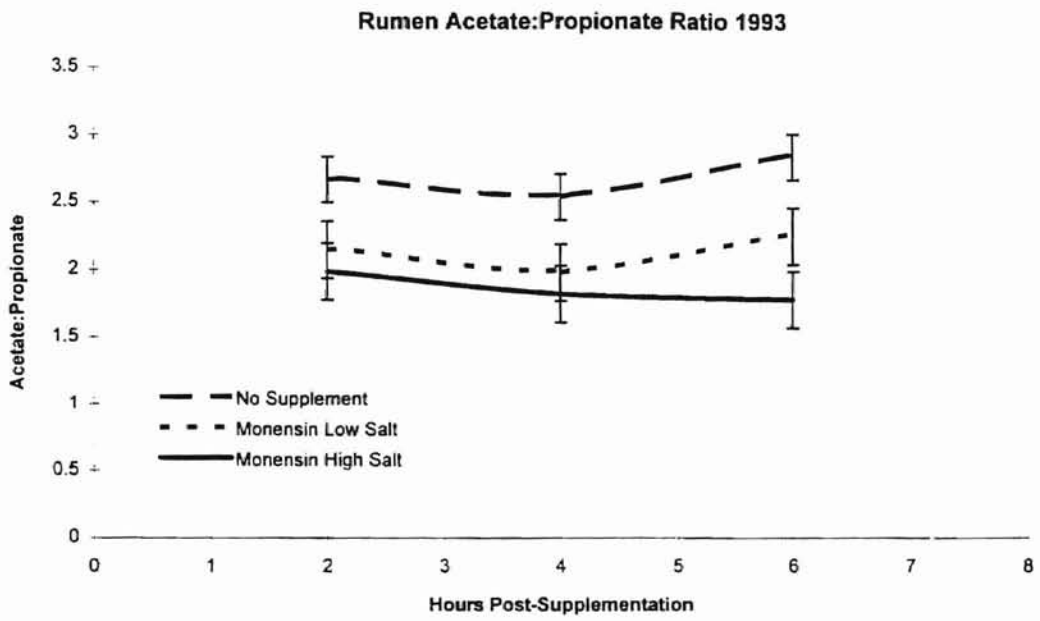

Isobutyrate mol/100mol 1994
mol/100mol
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt

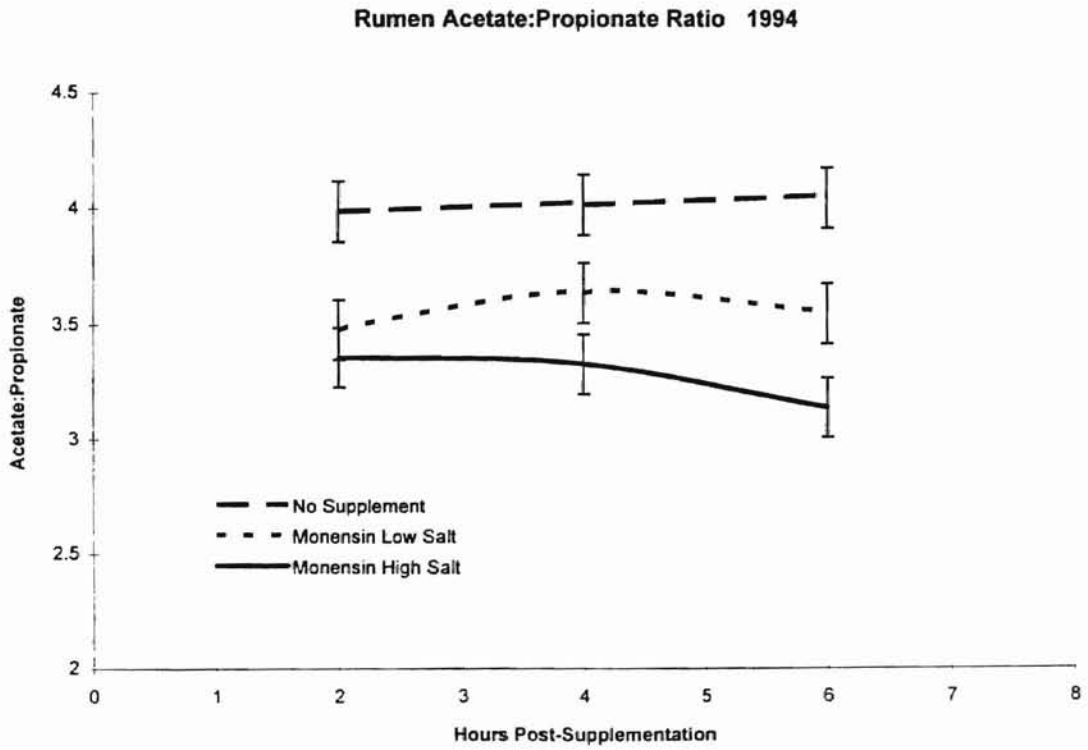

Valerate mol/100mol 1993
mol/100mol
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt


Valerate mol/100mol 1994
mol/100mol
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt


Isovalerate mol/100mol 1993
mol/100mol
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt


Isovalerate mol/100mol 1994
mol/100mol
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt


Rumen Acetate:Propionate Ratio 1993
Acetate:Propionate
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt


Rumen Acetate:Propionate Ratio 1994
Acetate:Propionate
4.5
4
3.5
3
2.5
2
0
1
2
3
4
5
6
7
8
Hours Post-Supplementation
No Supplement
Monensin Low Salt
Monensin High Salt

VITA

John Glen Andrae

Candidate for the Degree of

Master of Science

Thesis: ALTERNATE-DAY FEEDING OF A MONENSIN-CONTAINING ENERGY SUPPLEMENT TO GROWING CATTLE ON WHEAT PASTURE AND POTENTIATION OF THE MONENSIN RESPONSE BY SALT

Major Field: Animal Science

Biographical:

Personal Data: Born in Ballinger, Texas, July 31, 1971, the son of Allen and Gwen Andrae

Education: Earned Bachelor of Science Degree in Animal Science from Texas A&M University, College Station, Texas in May 1993. Completed the requirements for the Master of Science degree with a major in Animal Science at Oklahoma State University in May 1995.

Experience: Raised on a farm near Winters, Texas; owned and managed registered herd of Simmental cattle from 1985 to present. Employed by Rangeland Ecology and Management Department of Texas A&M University as an undergraduate and by Department of Animal Science as a graduate research assistant at Oklahoma State University.

Professional Memberships: American Society of Animal Science, Society for Range Management, and American Registry of Professional Animal Scientists.